明　細　書

窒化けい素回路基板および半導体モジュール

技術分野

本発明は、半導体実装回路基板や半導体パッケージ等として有用な窒化けい素回路基板および半導体モジュールに関する。

背景技術

近年、パワートランジスタモジュールなどの半導体モジュールやスイッチング電源モジュール等の比較的高電力を扱う半導体部品の搭載用基板等として、セラミックス基板上に銅板等の金属板（金属回路板）を接合したセラミックス回路基板が用いられている。

上述したようなセラミックス回路基板の製造工程におけるセラミックス基板と所定形状に打ち抜いた金属板との接合方法としては、Ｔｉ、Ｚｒ、Ｈｆ、Ｎｂ等の活性金属をＡｇ－Ｃｕろう材等に１～１０％含有した活性金属ろう材を用いる方法（活性金属法）や、金属板として酸素を１００～１０００ppm 含有するタフピッチ電解銅や表面を１～１０μmの厚さで酸化させた銅を用いてセラミックス基板と銅板とを直接接合させる、いわゆる直接接合法（ＤＢＣ法：ダイレクト・ボンディング・カッパー法）等が知られている。

例えば直接接合法においては、まず所定形状に打ち抜かれた厚さ０．３～０．５㎜の銅回路板を、酸化アルミニウム（Al_2O_3）焼結体や窒化アルミニウム（ＡｌＮ）焼結体等からなる厚さ０．６～１．０㎜セラミックス基板上に接触配置させて加熱し、接合界面にＣｕ－Cu_2Oの共晶液相を生成させ、この液相でセラミックス基板の表面を濡らした後、液相を冷却固化することによって、セラミックス基板と銅回路板とが直接接合される。このような直接接合法

を適用したセラミックス回路基板は、セラミックス基板と銅回路板との接合強度が強く、またメタライズ層やろう材層を必要としない単純構造なので小型高実装化が可能である等の長所を有しており、また製造工程の短縮化も図られている。

しかしながら、上述した直接接合法や活性金属法等により金属板をセラミックス基板に接合したセラミックス回路基板においては、大電流を流せるように金属板の厚さを0．3～0．5mmと厚くしている場合が多いため、熱履歴に対して信頼性に乏しいという問題があった。すなわち、熱膨張率が大きく異なるセラミックス基板と金属板とを接合すると、接合後の冷却過程や冷熱サイクルの付加により、上記熱膨張差に起因する熱応力が発生する。この応力は接合部付近のセラミックス基板側に圧縮と引張りの残留応力分布として存在し、特に金属板の外周端部と近接するセラミックス部分に残留応力の主応力が作用する。この残留応力は、セラミックス基板にクラックを生じさせたり、絶縁耐圧不良を起こしたり、あるいは金属板剥離の発生原因等となる。また、セラミックス基板にクラックが生じないまでも、セラミックス基板の強度を低下させるという悪影響を及ぼす。

また、最近の半導体素子の高密度化や高集積化に伴って、半導体モジュールや電子部品自体の小型化が進められている。このような状況に伴い、半導体実装基板にも小型化が求められている。

ここで、特に窒化アルミニウム基板は他のセラミックス基板と比較して高い熱伝導性と低熱膨張特性とを有するが、機械的強度の点で満足するものが得られていないため、回路基板の実装工程において付加されるわずかな押圧力や衝撃力によって、回路基板が破損し易く、半導体装置の製造歩留りが大幅に減少させる場合がある。

そのため従来の半導体モジュールにおいては、セラミックス基板の厚さを大きくすることおよび回路基板に対する補強部材を一体化することが必須の要件

となっていた。図４は、このような従来の半導体モジュール１０１の構造を示す断面図である。図４に示す半導体モジュール１０１は、厚さが大きく、熱伝導率が高いＡｌＮ焼結体から成るセラミックス基板１０２の表面側に金属回路板１０３を接合する一方、セラミックス基板１０２の下面側に裏銅板としての金属板１０４を一体に接合して形成される。また金属回路板１０３の所定位置には、半導体素子１０７が半田接合によって搭載されており、半導体素子１０７と金属回路板１０３の電極部とがボンディングワイヤ１０８によって電気的に接続されている。

上記のように組み立てられたセラミックス回路基板は、例えば銅から成る厚いヒートシンク板１０５の表面に半田接合により一体化されて図４に示すような半導体モジュール１０１が形成される。この半導体モジュール１０１は、取付ねじ１０６の締着によって機器ケーシング１０９や放熱フィンまたは実装ボード上に固着される。

しかしながら、上記従来の半導体モジュール１０１やセラミックス回路基板においては、放熱性を改善し、かつセラミックス基板の割れを防止するヒートシンク板が必須となる上に、割れに対する耐力を高めるために厚さが大きいセラミックス基板を使用する必要があるため、半導体モジュールとした場合のサイズが大きくなり、小型化が困難になる弊害があるとともに、セラミックス基板の製造コストが増加する難点があった。また基板厚さが増加するため、高熱伝導率のＡｌＮ基板を使用した場合においても、熱抵抗が大きくなり、期待する程に良好な放熱性が得られないという問題点もあった。

本発明は、このような課題に対処するためになされたもので、裏銅板（裏金属板）と、ヒートシンク板との両方は必要とせず構造が簡素で小型化でき、かつ放熱性および耐熱サイクル性等を改善した半導体モジュールを提供することを第１の目的としている。

一方、最近の半導体素子の高密度化や高集積化に伴って、半導体モジュール

や電子部品自体の小型化が求められていると共に、高実装化を計るために、実装部や回路構成部の面積の増大が求められている。

しかしながら、従来のセラミックス回路基板では、セラミックス基板の一方の主面を実装面として使用しているにすぎないため、実装部や回路構成部の増大を図るためにはセラミックス基板自体を大型化する必要があるが、セラミックス基板を大型化すると、銅回路板を接合する際にセラミックス基板に反りが生じ易くなる等の問題を招いてしまう。また、セラミックス基板の単純な大型化は、実装基板や電子部品自体に対する小型化要求に反することとなる。

上述したように、従来のセラミックス回路基板においては、実装部や回路構成部の面積を増大するにはセラミックス基板を大型化しなければならず、これに伴って銅回路板の接合不良を招いたり、電子部品の小型化要求に反する等の問題が生じている。また、半導体素子の多様化に伴って、半導体実装基板や半導体パッケージに対する要求特性も多岐に亘り、それら種々の要求を満足させることが求められている。

一方、半導体素子の高集積化、高出力化、大型化が進展し、素子から発熱する熱を効率的に系外に放散できる回路基板構造や熱応力に耐える高強度の回路基板構造を求める技術的要請が高まっている。そこでセラミックス基板として従来のアルミナ（Al_2O_3）基板よりも高強度を有する窒化けい素（Si_3N_4）基板を用いることも試行された。しかしながら、Si_3N_4基板は、靭性値などの機械的強度は優れているものの熱伝導性が窒化アルミニウム基板などと比較して著しく低いため、特に放熱性を要求される半導体用回路基板の構成材としては実用化されていない。

一方、窒化アルミニウム基板は他のセラミックス基板と比較して高い熱伝導性と低熱膨張特性とを有するが、機械的強度の点で満足するものが得られていないため、回路基板の実装工程において付加されるわずかな押圧力や衝撃力によって、回路基板が破損し易く、半導体装置の製造歩留りが大幅に減少させる

場合がある。

そのため従来のセラミックス回路基板においては、セラミックス基板の厚さを大きくすることが必須の要件となっていた。図７は、このような従来のセラミックス回路基板２０１の構造を示す断面図である。図７に示すセラミックス回路基板２０１は、厚さが大きく、熱伝導率が高いＡｌＮ焼結体から成る２枚のセラミックス基板２０２ａ，２０２ｂを金属回路板としての銅板２０４を介して接合し、さらにセラミックス基板２０２ｂ上面に銅板２０３を接合する一方、セラミックス基板２０２ａの下面側に裏銅板としての金属板２０５を一体に接合して形成される。また銅板２０３の所定位置には、半導体素子２０７が半田接合によって搭載されており、半導体素子２０７と銅板２０３の電極部とがボンディングワイヤ２０８によって電気的に接続されている。

このように、上記従来のセラミックス（ＡｌＮ）回路基板２０１においては、割れに対する耐力を高めるために厚さが大きいセラミックス基板２０２ａ，２０２ｂを使用する必要があるため、半導体モジュールとした場合のサイズが大きくなり、小型化が困難になる弊害があるとともに、セラミックス基板の製造コストが大幅に増加する難点があった。また基板厚さが増加するため、高熱伝導率のＡｌＮ基板を使用した場合においても、熱抵抗が大きくなり、期待する程に良好な放熱性が得られないという問題点もあった。

本発明は、このような課題に対処するためになされたもので、放熱性に優れ、実装部や回路構成部の面積の増大を図った上で小型化でき、さらに耐熱サイクル性等を改善した信頼性に優れる窒化けい素回路基板を提供することを第２の目的としている。

発明の開示

本発明に係る半導体モジュールは、熱伝導率が６０ｗ／ｍ・ｋ以上である高熱伝導性窒化けい素基板と、この高熱伝導性窒化けい素基板に搭載された半導

体素子と、この高熱伝導性窒化けい素基板の半導体素子搭載面側に接合された金属回路板と、上記高熱伝導性窒化けい素基板の半導体素子非搭載面側に接合され、かつ機器ケーシングあるいは実装ボードに接合される金属板とを具備することを特徴としている。

上述した本発明の半導体モジュールのより好ましい形態としては、機器ケーシングあるいは実装ボードに接合される金属板の厚さが前記金属回路板の厚さ以下である形態、機器ケーシングあるいは実装ボードに接合される金属板の厚さが前記金属回路板の厚さの２倍以上である形態、前記金属板が前記高熱伝導性窒化けい素基板に直接接合法により接合されている形態、さらには前記金属板が前記高熱伝導性窒化けい素基板に活性金属法により接合されている形態が挙げられる。

また本発明の窒化けい素回路基板は、熱伝導率が６０w／m・k以上である複数の高熱伝導性窒化けい素基板と、この高熱伝導性窒化けい素基板に接合された金属板とを具備し、前記複数の高熱伝導性窒化けい素基板が前記金属板を介して多層化された部分を有することを特徴としている。

上述した窒化けい素回路基板のより好ましい形態としては、前記金属板が前記高熱伝導性窒化けい素基板に直接接合法により接合されている形態、前記金属板が前記高熱伝導性窒化けい素基板に活性金属法により接合されている形態が挙げられる。

また本発明に係る窒化けい素回路基板は、熱伝導率が６０W／m・K以上である高熱伝導性窒化けい素基板と熱伝導率が６０W／m・K未満である基板とが同一平面上に配置されているとともに、少なくとも上記熱伝導率が６０W／m・K以上の高熱伝導性窒化けい素基板に金属回路板が接合されていることを特徴とする。

ここで上記熱伝導率が６０W／m・K未満の基板としては、アルミナ（Al_2O_3）基板や樹脂基板等を使用することができる。

また上記高熱伝導性窒化けい素基板および熱伝導率６０W／m・K未満の汎用で製造容易で安価な基板の裏面に形成した酸化層を介して金属板を接合するとよい。さらに金属板は酸化層を介して高熱伝導性窒化けい素基板および汎用で安価な基板の両方に亘って直接接合する構造でもよい。

すなわち、本発明の窒化けい素回路基板は、熱伝導性，強度，靭性に優れる窒化けい素基板と、汎用で製造容易で安価な基板とを組合せることによって、強度および放熱性を維持しながら製造容易で安価な回路基板、すなわち複合化した窒化けい素回路基板を得ることを可能にとしたものである。

上記高熱伝導性窒化けい素基板および熱伝導率が６０W／m・K未満である基板の配置形態は大別して３種類に分かれる。すなわち、同一平面上に両基板を隣接して配置する形態と、両基板を積層してサンドイッチ構造を有するように配置する形態と、アルミナ基盤や樹脂基板の表面に、複数の高熱伝導性窒化けい素基板を配置する形態とがあるが、要求特性に応じて上記各形態を併用してもよい。

例えば、高発熱部品である半導体素子を搭載する部位に高熱伝導性窒化けい素基板を配置することによって、回路基板全体の良好な放熱性を確保することができる。また機械的圧力や機械的応力等が直接作用する表面部を高強度・高靭性の窒化けい素基板で構成することによって、アッセンブリ工程での締め付け割れや熱サイクルの付加に伴うクラック発生等を抑制することが可能となる。

さらに上記窒化けい素回路基板において、前記高熱伝導性窒化けい素基板および前記汎用で製造容易で安価な基板の表面に形成したＴｉ，Ｚｒ，ＨｆおよびＮｂから選択される少なくとも１種の活性金属を含有する金属接合層を介して金属回路板を接合してもよい。

また高熱伝導性窒化けい素基板および汎用で製造容易で安価な基板の裏面に形成した金属接合層を介して金属板を接合してもよい。さらに金属回路板の厚さを金属板の厚さより大きく設定するとよい。また金属板は金属接合層を介し

て高熱伝導性窒化けい素基板および汎用で安価な基板の両方に亘って接合するとよい。さらに少なくとも１枚の金属回路板が金属接合層を介して高熱伝導性窒化けい素基板および汎用で安価な基板の両方に亘って接合されるように構成するとよい。

また本発明で使用する高熱伝導性窒化けい素基板は、希土類元素を酸化物に換算して、１．０～１７．５重量%、不純物陽イオン元素としてのＬｉ，Ｎａ，Ｋ，Ｆｅ，Ｃａ，Ｓｒ，Ｂａ，Ｍｎ，Ｂを合計で１．０重量%以下、好ましくは０．３重量%以下（検出限界としての０重量%を含む。）含有するように構成することができる。

なお、上記希土類元素酸化物の含有範囲である１．０～１７．５重量%は、数学的な表示として当然のことであるが、含有量の下限値である１．０重量%および上限値である１７．５重量%を含むものである。以下、他の成分範囲についても同様である。

また他の態様として高熱伝導性窒化けい素基板は、希土類元素を酸化物に換算して１．０～１７．５重量%含有し、窒化けい素結晶相および粒界相から成るとともに粒界相中における結晶化合物相の粒界相全体に対する割合が２０%以上、好ましくは５０%以上である窒化けい素焼結体から形成してもよい。

さらに上記希土類元素としてはランタノイド系列の元素を使用することが熱伝導率を向上させるために、特に好ましい。

また本発明において使用する高熱伝導性窒化けい素基板は、Ｔｉ，Ｚｒ，Ｈｆ，Ｖ，Ｎｂ，Ｔａ，Ｃｒ，Ｍｏ，Ｗからなる群より選択される少なくとも１種を酸化物に換算して０．１～３．０重量%含有することが好ましい。このＴｉ，Ｚｒ，Ｈｆ，Ｖ，Ｎｂ，Ｔａ，Ｃｒ，Ｍｏ，Ｗから成る群より選択される少なくとも１種は、酸化物、炭化物、窒化物、けい化物、硼化物として窒化けい素粉末に添加することにより含有させることができる。

さらに本発明で使用する高熱伝導性窒化けい素基板の製造方法は、酸素を１．

７重量%以下、不純物陽イオン元素としてのＬｉ，Ｎａ，Ｋ，Ｆｅ，Ｃａ，Ｓｒ，Ｂａ，Ｍｎ，Ｂを合計で１．０重量%以下、好ましくは０．３重量%以下、α相型窒化けい素を９０重量%以上含有し、平均粒径１．０μｍ以下の窒化けい素粉末に、希土類元素を酸化物に換算して１．０～１７．５重量%以下を添加した原料混合体を成形して成形体を調製し、得られた成形体を脱脂後、温度１８００～２１００℃で雰囲気加圧焼結し、上記焼結温度から、上記希土類元素により焼結時に形成された液相が凝固する温度までに至る焼結体の冷却速度を毎時１００℃以下にして徐冷することにより得ることができる。

上記製造方法によれば、窒化けい素結晶組織中に希土類元素等を含む粒界相が形成され、気孔率が２．５%以下、熱伝導率が６０Ｗ／ｍ・Ｋ以上、三点曲げ強度が室温で６５０ＭＰａ以上の機械的特性および熱伝導特性が共に優れた窒化けい素基板が得られる。

なお、本発明で使用する高熱伝導性窒化けい素基板において、上記不純物陽イオン元素の含有量が、数学的な意味において完全に０重量%となることは有り得ない。したがって、本願発明において規定する不純物イオン元素の含有量は、実質上、検出限界のレベルに拘らず検出限界としての０重量%を含むものである。

さらに、β相型と比較して焼結性に優れたα相型窒化けい素を９０重量%以上含有する窒化けい素原料粉末を使用することにより、高密度の窒化けい素基板を製造することができる。

また窒化けい素原料粉末に焼結助剤として添加する希土類元素としては、Ｈｏ，Ｅｒ，Ｙｂ，Ｙ，Ｌａ，Ｓｃ，Ｐｒ，Ｃｅ，Ｎｄ，Ｄｙ，Ｓｍ，Ｇｄなどの酸化物もしくは焼結操作により、これらの酸化物となる物質が単独で、または２種以上の酸化物を組み合せたものを含んでもよいが、特に酸化ホルミウム（Ho_2O_3），酸化エルビウム（Er_2O_3）が好ましい。

特に希土類元素としてランタノイド系列の元素であるＨｏ，Ｅｒ，Ｙｂを使

用することにより、焼結性あるいは高熱伝導化が良好になり、１８５０℃程度の低温度領域においても十分に緻密な焼結体が得られる。したがって焼成装置の設備費およびランニングコストを低減できる効果も得られる。これらの焼結助剤は、窒化けい素原料粉末と反応して液相を生成し、焼結促進剤として機能する。

上記焼結助剤の添加量は、酸化物換算で原料粉末に対して１．０～１７．５重量%の範囲とする。この添加量が１．０重量%未満の場合は、焼結体の緻密化が不十分であり、特に希土類元素がランタノイド系元素のように原子量が大きい元素の場合には、比較的低強度で比較的に低熱伝導率の焼結体が形成される。一方、添加量が１７．５重量%を超える過量となると、過量の粒界相が生成し、熱伝導率の低下や強度が低下し始めるので上記範囲とする。特に同様の理由により４～１５重量%とすることが望ましい。

また上記製造方法において他の選択的な添加成分として使用するＴｉ，Ｚｒ，Ｈｆ，Ｖ，Ｎｂ，Ｔａ，Ｃｒ，Ｍｏ，Ｗの酸化物，炭化物、窒化物、けい化物、硼化物は、上記希土類元素の焼結促進剤の機能を促進すると共に、結晶組織において分散強化の機能を果しSi_3N_4焼結体の機械的強度を向上させるものであり、特に、Ｈｆ，Ｔｉの化合物が好ましい。これらの化合物の添加量が０．１重量%未満の場合においては添加効果が不充分である一方、３．０重量%を超える過量となる場合には熱伝導率および機械的強度や電気絶縁破壊強度の低下が起こるため、添加量は０．１～３．０重量%の範囲とする。特に０．２～２重量%とすることが望ましい。

また上記Ｔｉ，Ｚｒ，Ｈｆ等の化合物は窒化けい素焼結体を黒色系に着色し不透明性を付与する遮光剤としても機能する。そのため、特に光によって誤動作を生じ易い集積回路等を搭載する回路基板を製造する場合には、上記Ｔｉ等の化合物を適正に添加し、遮光性に優れた窒化けい素基板とすることが望ましい。

また焼結体の気孔率は熱伝導率および強度に大きく影響するため２．５%以下となるように製造する。気孔率が２．５%を超えると熱伝導の妨げとなり、焼結体の熱伝導率が低下するとともに、焼結体の強度低下が起こる。

また、窒化けい素焼結体は組織的に窒化けい素結晶と粒界相とから構成されるが、粒界相中の結晶化合物相の割合は焼結体の熱伝導率に大きく影響し、本発明で使用する高熱伝導性窒化けい素基板においては、粒界相の２０%以上とすることが必要であり、より好ましくは５０%以上が結晶相で占めることが望ましい。

さらに上記のように高熱伝導性窒化けい素基板の気孔率を２．５%以下にし、また窒化けい素結晶組織に形成される粒界相の２０%以上が結晶相で占めるようにするためには、窒化けい素成形体を温度１８００～２１００℃で２～１０時間程度、加圧焼結し、かつ焼結操作完了直後における焼結体の冷却速度を毎時１００℃以下にして徐冷することが重要である。

焼結温度を１８００℃未満とした場合には、焼結体の緻密化が不充分で気孔率が２．５vol%以上になり機械的強度および熱伝導性が共に低下してしまう。一方焼結温度が２１００℃を超えると窒化けい素成分自体が蒸発分解し易くなる。特に加圧焼結ではなく、常圧焼結を実施した場合には、１８００℃付近より窒化けい素の分解蒸発が始まる。

上記焼結操作完了直後における焼結体の冷却速度は粒界相を結晶化させるために重要な制御因子であり、冷却速度が毎時１００℃を超えるような急速冷却を実施した場合には、焼結体組織の粒界相が非結晶質（ガラス相）となり、焼結体に生成した液相が結晶相として粒界相に占める割合が２０%未満となり、強度および熱伝導性が共に低下してしまう。

上記冷却速度を厳密に調整すべき温度範囲は、所定の焼結温度（１８００～２１００℃）から、前記の焼結助剤の反応によって生成する液相が凝固するまでの温度範囲で充分である。ちなみに前記のような焼結助剤を使用した場合の

液相凝固点は概略１６００～１５００℃程度である。そして少なくとも焼結温度から上記液相凝固温度に至るまでの焼結体の冷却速度を毎時１００℃以下、好ましくは５０℃以下、さらに好ましくは２５℃以下に制御することにより、粒界相の２０%以上、特に好ましくは５０%以上が結晶相になり、熱伝導率および機械的強度が共に優れた焼結体が得られる。

本発明において使用する高熱伝導性窒化けい素基板は、例えば以下のようなプロセスを経て製造される。すなわち前記所定の微細粒径を有し、また不純物含有量が少ない微細な窒化けい素粉末に対して所定量の焼結助剤、有機バインダ等の必要な添加剤および必要に応じてAl_2O_3やＡｌＮ，Ｔｉ化合物等を加えて原料混合体を調整し、次に得られた原料混合体を成形して所定形状の成形体を得る。原料混合体の成形法としては、汎用の金型プレス法、ドクターブレード法のようなシート成形法などが適用できる。上記成形操作に引き続いて、成形体を非酸化性雰囲気中で温度６００～８００℃、または空気中で温度４００～５００℃で１～２時間加熱して、予め添加していた有機バインダ成分を充分に除去し、脱脂する。次に脱脂処理された成形体を窒素ガス、水素ガスやアルゴンガスなどの不活性ガス雰囲気中で１８００～２１００℃の温度で所定時間雰囲気加圧焼結を行う。

上記製法によって製造された窒化けい素基板は気孔率が２．５%以下、６０Ｗ／ｍ・Ｋ（２５℃）以上の熱伝導率を有し、また三点曲げ強度が常温で６５０ＭＰａ以上と機械的特性にも優れている。

なお、低熱伝導性の窒化けい素に高熱伝導性のＳｉＣ等を添加して焼結体全体としての熱伝導率を６０Ｗ／ｍ・Ｋ以上にした窒化けい素基板は本発明の範囲には含まれない。しかしながら、熱伝導率が６０Ｗ／ｍ・Ｋ以上である窒化けい素焼結体に高熱伝導性のＳｉＣ等を複合させた窒化けい素系基板の場合には、本発明の範囲に含まれることは言うまでもない。

本発明に係る半導体モジュールは、上記のように製造した高熱伝導性窒化け

い素基板の表面および裏面に、前記直接接合法や活性金属法を用いて導電性を有する金属回路板および金属板をそれぞれ一体に接合して製造される。

本発明の半導体モジュールにおいては、セラミックス基板として、窒化けい素焼結体が本来的に有する高強度高靭性特性に加えて特に熱伝導率を大幅に改善した高熱伝導性窒化けい素基板を使用しているため、熱サイクルや組立て時の衝撃力によって基板に割れが発生することが少なく、裏銅板（裏金属板）と、放熱性や構造強度を高めるためのヒートシンク板との両方は必要としない。したがって、半導体モジュールの構造が簡素化されて製造コストが大幅に低減されるとともに、小型化でき高密度実装も可能となる。

また、基板に搭載する半導体素子等の発熱部品からの発熱は、高熱伝導性窒化けい素基板を経て迅速に系外に伝達されるため放熱性が極めて良好である。また、高強度高靭性である窒化けい素基板を使用しているため、モジュールの最大たわみ量を大きく確保することができる。そのため、アッセンブリ工程においてモジュールの締め付け割れが発生せず、半導体モジュールを用いた半導体装置を高い製造歩留りで安価に量産することが可能になる。

また高熱伝導性窒化けい素基板の靭性値が高いため、熱サイクルによって基板と金属板との接合部に割れが発生することが少なく、耐熱サイクル特性が著しく向上し、耐久性および信頼性に優れた半導体装置を提供することができる。

さらに高い熱伝導率を有する窒化けい素基板を使用しているため、高出力化および高集積化を指向する半導体素子を搭載した場合においても、熱抵抗特性の劣化が少なく、優れた放熱性を発揮する。

特に高熱伝導性窒化けい素基板自体の機械的強度が優れているため、要求される機械的強度特性を一定とした場合に、他のセラミックス基板を使用した場合と比較して基板厚さをより低減することが可能となる。この基板厚さを低減できることから熱抵抗値をより小さくでき、放熱特性をさらに改善することができる。また要求される機械的特性に対して、従来より薄い基板でも充分に対

応可能となるため、基板の製造コストをより低減することが可能となる。

また従来の高熱伝導性窒化アルミニウム基板のみを回路基板の構成材とした場合には、ある程度の機械的強度を確保するために窒化アルミニウム基板の厚さを大きく設定する必要があった。しかるに本発明の半導体モジュールや回路基板では、主として厚さが薄い高熱伝導性窒化けい素基板によって高い放熱性を確保すると同時に高強度特性を確保している。そのため、モジュール全体および回路基板全体をコンパクトに形成することができる。

一方、本発明に係る窒化けい素回路基板は、上記のように製造した複数の高熱伝導性窒化けい素基板の間，表面，および，必要に応じて裏面に、前記直接接合法や活性金属法を用いて導電性を有する金属板を一体に接合し多層化して製造される。

すなわち本発明の窒化けい素回路基板においては、銅回路板などの金属板を直接接合法または活性金属法により接合した複数の高熱伝導性窒化けい素基板を、金属板を介して多層化している。よって、立体的なアッセンブリが可能となることによって、実装部や回路構成部の面積の増大を図った上で小型化でき、小型高実装が達成できる。

また、銅板などの金属板を有する高熱伝導性窒化けい素基板を多層化することにより、パッケージ等を構成することができるだけでなく、銅板などの金属板を回路構成部として使用するため、従来の多層パッケージに比べて電流ロスが改善でき、また高周波型半導体素子や大電流型半導体素子等への対応が図れる効果が発揮される。

特に、セラミックス基板として、窒化けい素焼結体が本来的に有する高強度高靭性特性に加えて特に熱伝導率を大幅に改善した高熱伝導性窒化けい素基板を使用しているため、基板に搭載する半導体素子等の発熱部品からの発熱は、高熱伝導性窒化けい素基板を経て迅速に系外に伝達されるため放熱性が極めて良好である。また、高強度高靭性である窒化けい素基板を使用しているため、

回路基板の最大たわみ量を大きく確保することができる。そのため、アッセンブリ工程において回路基板の締め付け割れが発生せず、回路基板を用いた半導体装置を高い製造歩留りで安価に量産することが可能になる。

また熱伝導率が６０W／m・K以上の窒化けい素基板と６０W／m・K未満の基板とを複合化した窒化けい素回路基板において、高熱伝導性窒化けい素基板の厚さは、回路基板として使用した場合の要求特性に応じて種々の厚さに設定されるが、回路層の厚さの２倍以下に設定するとよい。窒化けい素基板の厚さが回路層の厚さの２倍を超えると、回路基板全体の厚さが増加し熱抵抗が大きくなる。窒化けい素基板の具体的な厚さは、０．２５～１．２㎜の範囲である。特に、この窒化けい素基板の厚さを０．８㎜以下に設定することにより、回路基板全体の厚さを低減することができ、回路基板の上下面間の熱抵抗差を、より効果的に減少させることが可能になり、回路基板全体の放熱性を、より改善することができる。

一方、本発明で使用される熱伝導率が６０W／m・K未満である基板は、特に限定されない。しかしながら、製造コストが低い観点から、特にアルミナ（Al_2O_3）基板や樹脂基板などの汎用で安価な基板が好適に使用できる。

本発明では上記熱伝導率が６０W／m・K以上の高熱伝導性窒化けい素基板と熱伝導率が６０W／m・K未満の汎用で安価な基板との２種類の基板を回路基板の要求特性に応じて使い分け、同一平面上にして複合基板を形成する。すなわち構造強度および放熱性が特に要求される部位には前記高熱伝導性窒化けい素基板を配置する一方、その他の部位には汎用で製造容易で安価な基板を同一平面上に配置することにより複合基板が形成される。

本発明に係る窒化けい素回路基板は、上記のように製造した複合基板の表面に、導電性を有する金属回路板を一体に接合し、さらにこの金属回路板を介して半導体素子を搭載して製造される。

さらに上記のように高熱伝導性窒化けい素基板と汎用で安価な基板とを同一

平面上で複合化した複合基板の裏面、すなわち金属回路板接合面と反対側の面に金属板を一体に接合するとよい。金属板は金属回路板と同様な材料で形成される。この金属板を一体に接合することにより、回路基板をヒートシンクなどの放熱部品に接合することが容易になるとともに、複合基板と金属回路板との熱膨張差に起因する回路基板の反りや変形を効果的に防止できる。

特に比較的に疎に形成される金属回路板の厚さを、密に形成される金属板の厚さより大きく設定することにより、複合化した複合基板の表裏に配設する金属量を同等にすることが可能であり、複合基板の表裏における熱膨張差が少なくなり、複合回路基板の反りや変形をより効果的に防止できる。

また少なくとも１枚の金属回路板または少なくとも１枚の金属板が、高熱伝導性窒化けい素基板および汎用で安価な基板の両方に亘って一体に接合される構造にすると、同一平面上に配置した窒化けい素基板と汎用で安価な基板とが相互に連結され、複合化した窒化けい素回路基板の一体性を高めることができる。

上記金属回路板および金属板の接合方法は、特に限定されず、以下に説明する直接接合法または活性金属法などを適用することができる。

直接接合法は、窒化けい素基板と汎用で安価な基板とから成る複合基板の表面に、厚さが０．５～１０μｍ程度の酸化層を形成し、この酸化層を介して、回路層となる金属回路板や金属板を上記複合基板に直接接合する方法である。ここで上記金属回路板や金属板は、ろう材などの接合剤を使用せずに複合基板表面に直接的に接合される。すなわち、金属回路板の成分と基板成分との共晶化合物を加熱により発生せしめ、この共晶化合物を接合剤として両部材が接合される。

なお、この直接接合法はAl_2O_3などの酸化物系セラミックスについてのみ適用可能であり、窒化けい素基板や窒化アルミニウム基板などの非酸化物系セラミックスにそのまま適用しても基板に対する濡れ性が低いため、金属回路板

の充分な接合強度が得られない。

そこで窒化けい素基板および窒化アルミニウム基板の表面に予め酸化層を形成し、基板に対する濡れ性を高める必要がある。この酸化層は上記窒化けい素基板および窒化アルミニウム基板を、空気中などの酸化雰囲気中で温度１０００～１４００℃程度で０．１～４８時間加熱して形成される。この酸化層の厚さが０．５μｍ未満の場合には、上記濡れ性の改善効果が少ない一方、１０μｍを超えるようにしても改善効果が飽和するとともに、却って熱伝導率が低下し易くなるため、酸化層の厚さは０．５～１０μｍの範囲、より好ましくは１～５μｍの範囲とする。

上記Si_3N_4基板の酸化層は、当初Si_3N_4基板成分の酸化物であるSiO_2のみから構成されているが、加熱による金属回路板の接合操作時において、Si_3N_4基板に焼結助剤として添加されていた希土類元素酸化物が酸化層方向に拡散移動する結果、希土類酸化物が酸化層中に濃縮された構成となる。例えば焼結助剤としてY_2O_3を使用した場合には加熱接合操作後の酸化層は、Y_2O_3を１～２０重量%程度含有するイットリアシリケートなどのSiO_2－Y_2O_3化合物から構成されるようになる。一方、汎用で安価な基板としてＡｌＮ基板を使用する場合においては、ＡｌＮ基板の酸化層はAl_2O_3から構成される。

上記金属回路板や金属板を構成する金属としては、銅，アルミニウム，鉄，ニッケル，クロム，銀，モリブデン，コバルトの単体またはその合金など、基板成分との共晶化合物を生成し、直接接合法を適用できる金属であれば特に限定されないが、特に導電性および価格の観点から銅，アルミニウムまたはその合金が好ましい。

金属回路板（回路層）の厚さは、通電容量等を勘案して決定されるが、窒化けい素基板の厚さを０．２５～１．２㎜の範囲とする一方、金属回路板の厚さを０．１～０．５㎜の範囲に設定して両者を組み合せると熱膨張差による変形

などの影響を受けにくくなる。

そして、金属回路板や金属板が銅回路板である場合には、以下のように接合操作が実施される。すなわち酸化層を形成した窒化けい素基板および汎用で安価な基板の表面の所定位置に、銅回路板を接触配置して基板方向に押圧した状態で、銅の融点（１０８３℃）未満の温度で、かつ銅－酸化銅の共晶温度（１０６５℃）以上に加熱し、生成したＣｕ－Ｏ共晶化合物液相を接合剤として銅回路板等が窒化けい素基板および汎用で安価な基板の表面に直接的に接合される。この直接接合法は、いわゆる銅直接接合法（ＤＢＣ：Direct Bonding Copper 法）である。さらにSi_3N_4基板上に直接接合した銅回路板の所定位置に半導体素子（Ｓｉチップ）を半田接合して搭載することにより、本発明に係る窒化けい素回路基板が製造される。なお汎用で安価な基板としてAl_2O_3基板のような酸化物系セラミックス基板を使用する場合には、上記のような酸化層を形成する必要がないことは言うまでもない。

一方、金属回路板や金属板がアルミニウム回路板である場合には、Si_3N_4基板および汎用で安価な基板表面にＡｌ回路板を押圧した状態でアルミニウム－けい素の共晶温度以上に加熱し、生成したＡｌ－Ｓｉ共晶化合物を接合剤としてＡｌ回路板がSi_3N_4基板表面に直接的に接合される。そしてSi_3N_4基板上に直接接合したＡｌ回路板の所定位置に半導体素子を半田接合して搭載することにより、本発明の窒化けい素回路基板が製造される。

このように直接接合法を使用して金属回路板を複合基板表面に直接接合し、さらに複数の半導体素子をSi_3N_4基板上の金属回路板上に搭載して形成した本発明に係る窒化けい素回路基板によれば、金属回路板とSi_3N_4基板または汎用で安価な基板との間に、接着剤やろう材のような介在物が存在しないため、両者間の熱抵抗が小さく、金属回路板上に設けられた半導体素子の発熱を系外に迅速に放散させることが可能である。

次に活性金属法による金属回路板等の接合方法を説明する。

活性金属法では、Ｔｉ，Ｚｒ，ＨｆおよびＮｂから選択される少なくとも１種の活性金属を含有し適切な組成比を有するＡｇ－Ｃｕ－Ｔｉ系ろう材等で複合基板表面に、厚さ２０μｍ前後の金属接合層（活性金属ろう材層）を形成し、この金属接合層を介して、銅回路板などの金属回路板や金属板が接合される。活性金属は、基板に対するろう材の濡れ性を改善し、接合強度を高める作用を有する。活性金属ろう材の具体例としては、重量％で上記活性金属を１～１０％，Ｃｕを１５～３５％，残部が実質的にＡｇから成るろう材組成物が好適である。上記金属接合層は、このろう材組成物を有機溶媒中に分散して調製した接合用組成物ペーストを複合基板表面にスクリーン印刷する等の方法で形成される。

そしてスクリーン印刷した金属接合層上に、回路層となる金属回路板や金属板を接触配置した状態で、真空中または不活性ガス雰囲気中で、例えばＡｇ－Ｃｕ共晶温度（７８０℃）以上で、かつ金属回路板の融点（銅の場合は１０８３℃）以下の温度に加熱することにより、金属回路板が金属接合層を介して複合基板に接合される。

なお、上記の回路基板においては金属回路板や金属板を直接接合法や活性金属法を使用して複合基板上に一体に接合して回路層を形成しているが、メタライズ法によって回路層を形成することも可能である。すなわち、メタライズ法では、例えばモリブデン（Ｍｏ）やタングステン（Ｗ）などの高融点金属とＴｉやその化合物とを主成分とするメタライズ組成物を複合基板表面に焼き付けて、厚さ１５μｍ程度の回路層としての高融点金属メタライズ層を形成する方法である。

このメタライズ法により、回路層を形成する場合には、メタライズ層表面にさらにＮｉやＡｕから成る厚さ３～５μｍ程度の金属めっき層を形成することが好ましい。この金属めっき層を形成することにより、メタライズ層の表面平滑性が改善され、半導体素子との密着性がより改善されるとともに、半田濡れ

性が向上するため、半田を使用した半導体素子の接合強度をより高めることができる。

上記構成に係る窒化けい素回路基板によれば、窒化けい素焼結体が本来的に有する高強度高靭性特性に加えて特に熱伝導率を大幅に改善した高熱伝導性窒化けい素基板を、特に構造強度および放熱性が要求される部位に配置する一方、その他の部位にアルミナ基板や樹脂基板のように汎用で製造容易で安価な基板を配置し、両基板を同一平面上に配置して複合基板とし、この複合基板の表面に金属回路板を一体に接合し、さらに高熱伝導性窒化けい素基板上に接合した金属回路板上に半導体素子を搭載して形成されている。

したがって、製造コストが安価であり、また半導体素子等の発熱部品からの発熱は熱伝導率が高い窒化けい素基板を経て迅速に系外に伝達されるため放熱性が極めて良好である。また、高強度高靭性である高熱伝導率窒化けい素基板を、特に構造強度が要求される部位に配置することにより、回路基板の最大たわみ量を大きく確保することができる。そのため、アッセンブリ工程において回路基板の締め付け割れが発生せず、回路基板を用いた半導体装置を高い製造歩留りで安価に量産することが可能になる。

また窒化けい素基板の靭性値が高いため、熱サイクルによって基板と金属回路板や金属板との接合部に割れが発生することが少なく、耐熱サイクル特性が著しく向上し、耐久性および信頼性に優れた半導体装置を提供することができる。

さらに高い熱伝導率を有する窒化けい素基板を使用しているため、高出力化および高集積化を指向する半導体素子を搭載した場合においても、熱抵抗特性の劣化が少なく、優れた放熱性を発揮する。

特に窒化けい素基板自体の機械的強度が優れているため、要求される機械的強度特性を一定とした場合に、他のセラミックス基板を使用した場合と比較して基板厚さをより低減することが可能となる。この基板厚さを低減できること

から熱抵抗値をより小さくでき、放熱特性をさらに改善することができる。また要求される機械的特性に対して、従来より薄い基板でも充分に対応可能となるため、基板製造コストをより低減することが可能となる。

また従来の高熱伝導性窒化アルミニウム基板のみを回路基板の構成材とした場合には、ある程度の機械的強度を確保するために窒化アルミニウム基板の厚さを大きく設定する必要があった。しかるに本発明の回路基板では、主として窒化けい素基板によって高い放熱性を確保すると同時に高強度特性を確保している。そして、特に窒化けい素基板の厚さに、アルミナ基板や樹脂基板などの汎用で製造容易で安価な基板の厚さを揃えて小さく形成することが可能となるため、汎用で安価な基板部の熱抵抗値をさらに相乗的に低減することが可能となる。したがって本発明によれば、同じ熱伝導率を有する従来の汎用で安価な基板のみを使用した従来の回路基板と比較して、放熱性をさらに高めることができる。

図面の簡単な説明

第１図は本発明の一実施例に係る半導体モジュールの構造を示す断面図である。

第２図は本発明の他の実施例に係る半導体モジュールの断面図である。

第３図は本発明の他の実施例に係る半導体モジュールの断面図である。

第４図は従来の半導体モジュールの構造を示す断面図である。

第５図は本発明の一実施例に係る窒化けい素回路基板の構造を示す断面図である。

第６図は本発明の他の実施例に係る窒化けい素回路基板の断面図である。

第７図は従来のセラミックス回路基板の構造を示す断面図である。

第８図は本発明に係る窒化けい素回路基板の構成例を示す平面図である。

第９図は本発明に係る窒化けい素回路基板の一実施例を示す断面図であり、

図８におけるIX－IX矢視断面図である。

第１０図は本発明に係る窒化けい素回路基板の他の実施例を示す断面図であり、図８におけるＸ－Ｘ矢視断面図である。

発明を実施するための最良の形態

次に本発明の実施形態について、以下に示す実施例および添付図面を参照して具体的に説明する。まず本発明において使用する高熱伝導性窒化けい素基板について述べ、しかる後に、この高熱伝導性窒化けい素基板をセラミックス基板として使用した半導体モジュールおよび窒化けい素回路基板について説明する。

まず本発明の半導体モジュールおよび窒化けい素回路基板の構成材となる各種高熱伝導性窒化けい素基板を以下の手順で製造した。

すなわち、酸素を１．３重量%、前記不純物陽イオン元素を合計で０．１５重量%含有し、α相型窒化けい素９７%を含む平均粒径０．５５μmの窒化けい素原料粉末に対して、表１～３に示すように、焼結助剤としてのY_2O_3，Ho_2O_3などの希土類酸化物と、必要に応じてＴｉ，Ｈｆ化合物，Al_2O_3粉末，ＡｌＮ粉末とを添加し、エチルアルコール中で窒化けい素製ボールを用いて７２時間湿式混合した後に乾燥して原料粉末混合体をそれぞれ調整した。次に得られた各原料粉末混合体に有機バインダを所定量添加して均一に混合した後に、１０００kg／cm^2の成形圧力でプレス成形し、各種組成を有する成形体を多数製作した。

次に得られた各成形体を７００℃の雰囲気ガス中において２時間脱脂した後に、この脱脂体を表１～３に示す焼結条件で緻密化焼結を実施した後に、焼結炉に付設した加熱装置への通電量を制御して焼結炉内温度が１５００℃まで降下するまでの間における焼結体の冷却速度がそれぞれ表１～３に示す値となるように調整して焼結体を冷却し、それぞれ試料１～５１に係る窒化けい素焼結

体を調製した。さらに得られた焼結体を切断して厚さが0．3㎜，0．5㎜および0．6㎜の所定形状の高熱伝導性窒化けい素基板とした。

こうして得た試料1～51に係る各窒化けい素基板について気孔率、熱伝導率（25℃）、室温での三点曲げ強度の平均値を測定した。さらに、各窒化けい素基板についてX線回折法によって粒界相に占める結晶相の割合を測定し、下記表1～3に示す結果を得た。

【表1】

試料	原料組成（重量%）		焼結条件	焼結後の1500℃までの冷却速度	気孔率	粒界相において結晶相が占める割合(面積比)(%)	熱伝導率	三点曲げ強度
	Si_3N_4	Ho_2O_3	温度×時間 (℃)(hr)	(℃/hr)	(%)		(W/m・K)	(MPa)
1	92	8	1950×6	100	0.2	22	89	845
2	92	8	1950×6	50	0.1	28	92	820
3	92	8	1900×6	50	0.6	34	95	800
4	90	10	1950×6	100	0.5	25	95	820
5	90	10	1950×6	25	0.3	65	99	705
6	90	10	1900×6	25	0.9	67	104	805
7	87.5	12.5	1975×6	50	0.4	69	114	760
8	87.5	12.5	1900×6	25	1.2	70	105	795
9	85	15	1950×6	100	1.2	40	102	780
10	85	15	2000×6	100	0.6	35	108	700
11	85	15	1950×6	25	1.0	65	120	730
12	82.5	17.5	1950×6	100	2.3	30	90	755
13	82.5	17.5	2000×6	100	1.8	28	96	700
14	82.5	17.5	2000×6	25	1.4	32	100	680

【表2】

試料	原料組成（重量%）					焼結条件	焼結後の1500℃までの冷却速度 (℃/hr)	気孔率 (%)	粒界相における結晶相占める割合 (面積比) (%)	熱伝導率 (W/m-K)	三点曲げ強度 (MPa)
	Si_3N_4	Y_2O_3	他成分	Al_2O_3	AlN	温度×時間 (℃) (hr)					
15	94.8	5	HfO_2 0.2			1900×6	50	1.3	50	88	840
16	94	5	HfO_2 1			1900×6	50	0.2	55	90	960
17	92	5	HfO_2 3			1900×6	50	0.1	45	75	1060
18	95	2	HfO_2 3			1900×6	50	0.5	30	65	930
19	92	7.5	HfO_2 0.5			1900×6	50	0.1	75	95	870
20	94	5	HfO_2 1			1900×6	100	0.2	45	80	980
21	94	5	HfC 1			1900×6	100	0.3	55	92	960
22	94	5	HfN 1			1950×6	100	0.4	55	90	930
23	94	5	$HfSi_2$ 1			1950×6	100	0.4	50	88	910
24	94	5	HfB_2 1			1900×6	100	0.4	45	83	880
25	94	5	TiO_2 1			1900×6	100	0.2	48	80	960
26	94	5	ZrO_2 1			1900×6	100	0.2	45	85	1030
27	94	5	V_2O_5 1			1900×6	100	0.3	50	90	930
28	94	5	Nb_2O_5 1			1900×6	100	0.2	48	83	880
29	94	5	Ta_2O_5 1			1900×6	100	0.4	45	80	900
30	94	5	Cr_2O_3 1			1900×6	100	0.2	58	100	930
31	94	5	MoO_3 1			1900×6	100	0.4	40	75	910
32	94	5	WO_3 1			1900×6	100	0.3	40	75	880
33	94	5	TiC 1			1900×6	100	0.4	59	95	930
34	94	5	WC 1			1900×6	100	0.3	49	83	910
35	94	5	TiB_2 1			1900×6	100	0.4	40	80	950
36	94	5	$HfO2$ 0.5 TiO_2 0.5			1900×6	100	0.2	46	82	1000

【表3】

試料	原料組成（重量%）						焼結条件 温度×時間 (℃) (hr)	焼結後の1500℃までの冷却速度 (℃/hr)	気孔率 (%)	粒界相において結晶相が占める割合 (面積比) (%)	熱伝導率 (W/m・k)	三点曲げ強度 (MPa)
	Si_3N_4	希土類酸化物		他成分	Al_2O_3	AlN						
37	88	Ho_2O_3	6.5	HfO_2 2			1900×6	50	0.2	55	120	720
		Y_2O_3	3.5									
38	88	Er_2O_3	6.5	HfO_2 2			1900×6	50	0.1	54	119	775
		Y_2O_3	2.5									
39	88	Yb_2O_3	6.5	HfO_2 2			1900×6	50	0.2	60	125	750
		Y_2O_3	3.5									
40	83.9	Ho_2O_3	15	HfO_2 1	0.1		1900×6	50	0.1	49	106	770
41	84	Ho_2O_3	15	HfO_2 0.5	0.5		1900×6	50	0.1	30	90	850
42	82	Ho_2O_3	15	HfO_2 2	1		1850×6	25	0.1	22	82	900
43	82.5	Ho_2O_3	15	HfO_2 2		0.5	1900×6	50	0.1	39	100	880
44	83	Ho_2O_3	15	HfO_2 2		1	1800×6	50	0.1	24	88	870
45	82.6	Ho_2O_3	15	HfO_2 2	0.2	0.2	1900×6	50	0.1	37	100	885
46	82.5	Er_2O_3	15	HfO_2 2	0.5		1900×6	50	0.1	40	94	850
47	82.5	Er_2O_3	15	HfO_2 2		0.5	1900×6	50	0.1	38	93	825
48	89.8	Y_2O_3	8	HfO_2 2	0.2		1900×6	50	0.1	36	95	800
49	84	Ho_2O_3	15	TiO_2 0.5	0.5		1900×6	50	0.1	28	88	820
50	84	Er_2O_3	15	TiO_2 0.5	0.5		1900×6	50	0.1	27	88	810
51	84	Yb_2O_3	12.5	TiO_2 0.5	0.5		1900×6	50	0.1	27	90	700

表１～３に示す結果から明らかなように試料１～５１に係る窒化けい素焼結体においては、原料組成および不純物量を適正に制御し、従来例と比較して緻密化焼結完了直後における焼結体の冷却速度を従来より低く設定しているため、粒界相に結晶相を含み、結晶相の占める割合が高い程、高熱伝導率を有する放熱性の高い高強度窒化けい素基板が得られた。

これに対して酸素を１．３～１．５重量%，前記不純物陽イオン元素を合計で０．１３～１．５０重量%含有し、α相型窒化けい素を９３%含む平均粒径０．６０μmの窒化けい素原料粉末を用い、この窒化けい素粉末に対してY_2O_3（酸化イットリウム）粉末を３～６重量と、アルミナ粉末を１．３～１．６重量%添加した原料粉末を成形，脱脂後、１９００℃で６時間焼結し、焼結後、工業上通常行われる炉冷（冷却速度：毎時４００℃）を行った。得られた焼結体の熱伝導率は２５～２８W／m・Kと低く、従来の一般的な製法によって製造された窒化けい素焼結体の熱伝導率に近い値となった。

次に得られた試料１～５１に係る厚さ０．５㎜の高熱伝導性窒化けい素基板の両面に、直接接合法または活性金属法を用いて金属回路板および金属板を一体に接合することにより、それぞれ半導体モジュールを製造した。

図１は、本発明の一実施例による半導体モジュール１ａの構造を示す断面図である。

図１において、高熱伝導性窒化けい素基板１０の表面には金属回路板としての銅板３が一体に接合されており、また高熱伝導性窒化けい素基板１０の裏面には金属板として銅板４ａが接合されており、これらにより半導体モジュール１ａが構成されている。

また、図１に示す半導体モジュール１ａにおける銅板３，４ａは、高熱伝導性窒化けい素基板１０に対して直接接合法、いわゆるＤＢＣ法により接合されている。このようなＤＢＣ法を利用する場合の銅板３，４ａとしては、タフピッチ銅のような酸素を１００～３０００ppm の割合で含有する銅を用いること

が好ましいが、表面を酸化させた無酸素銅を用いることも可能である。なお、銅や銅合金の単板に代えて、高熱伝導性窒化けい素基板１０との接合面が少なくとも銅により構成されている他の金属部材とのクラッド板等を用いることもできる。

高熱伝導性窒化けい素基板１０の表面側に接合された銅板３は、半導体部品等の実装部となるものであり、所望の回路形状にパターニングされている。銅板３の所定位置には半導体素子７が半田接合されており、半導体素子７の電極部と銅板３の電極部とはボンディングワイヤ８によって電気的に接続されている。また、高熱伝導性窒化けい素基板１０の裏面側に接合された銅板４ａは、接合時における高熱伝導性窒化けい素基板１０の反り等を防止するものであり、中央付近から２分割された状態でほぼ高熱伝導性窒化けい素基板１０の裏面全面に接合、形成されている。図１に示すように、裏面側の銅板４ａの厚さt_1は、半導体部品等の実装部となる金属回路板としての銅板３と同じ厚さのものを使用してもよいが、銅板３の厚さt_0以下、さらに銅板３の厚さt_0の７０～９０%の厚さの銅板を使用することが好ましい。

一方、高熱伝導性窒化けい素基板１０の裏面に接合する金属板４ｂに、放熱性を改善するヒートシンク板としての機能を付与する場合においては、図３に示すように、機器ケーシング９あるいは実装ボードに接合される金属板４ｂの厚さt_2を前記金属回路板の厚さt_0の２倍以上とすることが好ましい。上記高熱伝導性窒化けい素基板１０の裏面側に接合する金属板４ｂの厚さt_2を、金属回路板３の厚さt_0の２倍以上とすることにより、たとえヒートシンク板を用いなくても、この金属板４ｂがヒートシンクとして機能する効果を大きくすることができるため、モジュールの放熱性をより改善することが可能となる。

ここで、図１に示した半導体モジュール１ａは、高熱伝導性窒化けい素基板１０に銅板３，４ａをＤＢＣ法により接合したものであるが、例えば銅板３，４ａを活性金属法で高熱伝導性窒化けい素基板１０に接合した半導体モジュー

ルであってもよい。上記活性金属法は、例えばＴｉ、Ｚｒ、Ｈｆ、Ｎｂ等から選ばれた少なくとも１種の活性金属を含むろう材（以下、活性金属含有ろう材と記す）層を介して、高熱伝導性窒化けい素基板１０と銅板３，４ａとを接合する方法である。用いる活性金属含有ろう材の組成としては、例えばＡｇ－Ｃｕの共晶組成（７２wt%Ａｇ－２８wt%Ｃｕ）もしくはその近傍組成のＡｇ－Ｃｕ系ろう材やＣｕ系ろう材を主体とし、これに１～１０重量%のＴｉ、Ｚｒ、Ｈｆ、Ｎｂ等から選ばれた少なくとも１種の活性金属を添加した組成等が例示される。なお、活性金属含有ろう材にＩｎを１～１０重量%添加して用いることもできる。

図１に示した半導体モジュール１ａのように、銅板３，４ａを高熱伝導性窒化けい素基板１０にＤＢＣ法で接合したものは、単純構造で高接合強度が得られ、また製造工程を簡易化できる等の利点を有する。一方、銅板３，４ａを高熱伝導性窒化けい素基板１０に活性金属法で接合した半導体モジュールは、高接合強度が得られると共に、活性金属含有ろう材層が応力緩和層としても機能するため、より信頼性の向上が図れる。このようなことから、要求特性や用途等に応じて接合法を選択することが好ましい。

また、活性金属法により高熱伝導性窒化けい素基板１０に金属回路板および金属板を接合する場合には、銅板に限らず、用途に応じて各種の金属板、例えばニッケル板、タングステン板、モリブデン板、これらの合金板やクラッド板（銅板とのクラッド板を含む）等を用いることも可能である。

上述した半導体モジュール１ａは、例えば以下のようにして製造される。すなわち、例えばタフピッチ銅のような酸素含有銅板を、所定形状（銅板３に関しては回路パターン形状）に加工し、得られた銅板３，４ａを高熱伝導性窒化けい素基板１０の表面にそれぞれ接触配置し、銅の融点（１３５６Ｋ）以下で銅と酸化銅との共晶温度（１３３８Ｋ）以上の温度で加熱することにより、各銅板３，４ａを接合し、さらに銅板３の所定位置に半導体素子７を半田接合し、

半導体素子７の電極と銅板３の電極とをボンディングワイヤ８によって接続して半導体モジュールを作製する。この銅板を加熱接合する際の雰囲気は、銅板として酸素含有銅板を使用する場合には不活性ガス雰囲気とすることが好ましい。

また、活性金属法により金属回路板および金属板を接合した半導体モジュールは、例えば以下のようにして製造される。まず、上記半導体モジュール１ａと同様に、所定形状の銅板３，４ａを用意する。一方、前述したような活性金属含有ろう材をペースト化したものを、例えば高熱伝導性窒化けい素基板１０の表面に塗布する。ろう材層の塗布厚は、冷熱サイクル特性の向上を図る上で、加熱接合後のろう材層の層厚があまり厚くならないようにすることが好ましい。次に、ろう材ペーストを塗布した高熱伝導性窒化けい素基板１０の表面上に、銅板３，４ａをそれぞれ積層配置し、使用したろう材に応じた温度で熱処理することにより、金属回路板３および金属板４ａを接合し、さらに銅板３の所定位置に半導体素子７を半田接合し、半導体素子７の電極と銅板３の電極とをボンディングワイヤ８によって接続して半導体モジュールを作製する。

また、図１に示した半導体モジュール１ａは、窒化けい素基板１０の外縁部に形成した取付ねじ用貫通孔１１に取付ねじ６ａを挿通して機器ケーシング９等に締着固定される。しかしながら、窒化けい素焼結体は硬度が高く孔明け加工が容易ではない。そこで製造工程を簡略化するために、例えば図２に示すように、取付ねじ用貫通孔１１ａを形成した枠状のケース１２を用意し、このケース１２の内周縁部を半導体モジュールの外周縁部に押圧し、取付ねじ６ｂによってモジュールを機器ケーシング９等に圧接して固定することも可能である。

上述したような構造の半導体モジュールにおいては、セラミックス基板として、窒化けい素焼結体が本来的に有する高強度高靭性特性に加えて特に熱伝導率を大幅に改善した高熱伝導性窒化けい素基板１０を使用しているため、熱サイクルや組立時の衝撃力によって基板１０に割れが発生することが少なく、特

に、放熱性や構造強度を高めるためのヒートシンク板を必要としない。したがって、半導体モジュールの構造が簡素化されて、製造コストが大幅に低減されるとともに、小型化でき高密度実装も可能となり、半導体装置のダウンサイジングを効果的に達成することができる。

次に、実施例の具体例およびその評価結果について述べる。

実施例1

まず、高熱伝導性窒化けい素基板として、前記表1～3に示す試料1～51に係る窒化けい素基板を採用し、空気中で酸化することにより、表面に厚さ4μmの酸化物層（SiO_2 層）を有する厚さ0．5mmの高熱伝導性窒化けい素基板10を用意すると共に、プレス加工により形成した、タフピッチ銅（酸素含有量：300ppm）からなる所定形状の厚さ0．3mmの金属回路板としての銅板3および厚さ0．25mmの金属板としての銅板4aを用意した。

そして、図1に示したように、高熱伝導性窒化けい素基板10の両面に2枚の銅板3，4aをそれぞれ直接接触配置し、窒素ガス雰囲気中にて1348Kの条件で加熱して接合させ、さらに半導体素子7を銅板3上に半田接合し、ワイヤボンディングを施して目的とする半導体モジュール1aを得た。

一方、比較例として、上記高熱伝導性窒化けい素基板10に代えて、厚さ0．6mmの窒化アルミニウム基板を使用した点以外は、実施例1と同様に処理して比較例に係る半導体モジュールを製造した。

このようにして得た実施例1に係る半導体モジュール1aおよび比較例の半導体モジュールに対して熱サイクル試験（TCT：233K×30分+RT×10分+398K×30分を1サイクルとする）を施し、セラミックス基板における割れの発生割合を測定した。その結果、実施例1の半導体モジュールは、100サイクルのTCT後においてもクラックが発生しなかったのに対して、比較例による半導体モジュールは100サイクルでセラミックス基板の5～9%にクラックが生じた。

実施例2

高熱伝導性窒化けい素基板として、試料1～51に係る厚さ0．5㎜の高熱伝導性窒化けい素基板10を用意すると共に、実施例1と同一形状であり、プレス加工により形成した所定形状の厚さ0．3㎜の銅板3，4と厚さ0．25㎜の銅板5とを用意した。

そして、高熱伝導性窒化けい素基板10の両面に、In：Ag：Cu：Ti＝14．0：59．0：23．0：4．0組成の活性金属含有ろう材をペースト化したものを塗布し、この塗布層を介して銅板3，4aを積層配置した後、窒素ガス雰囲気中にて加熱して接合させ、さらに半導体素子7を銅板3上に半田接合し、ワイヤボンディングを施して目的とする半導体モジュールを得た。

このようにして得た半導体モジュールに対して熱サイクル試験を実施例1と同一条件下で実施したところ、実施例1と同様な良好な結果が得られ、冷熱サイクルに対する信頼性に優れることを確認した。

実施例3

まず、高熱伝導性窒化けい素基板として、前記試料1～51に係る窒化けい素基板を採用し、空気中で酸化することにより、表面に厚さ4μmの酸化物層（SiO_2 層）を有する厚さ0．5㎜の高熱伝導性窒化けい素基板10を用意すると共に、プレス加工により形成した、タフピッチ銅（酸素含有量：300ppm）からなる所定形状の厚さ0．3㎜の銅板3および厚さ0．6㎜の銅板4bを用意した。

そして、図3に示すように、高熱伝導性窒化けい素基板10の両面に2枚の銅板3，4bをそれぞれ直接接触配置し、窒素ガス雰囲気中にて1348Kの条件で加熱して接合させ、さらに半導体素子7を銅板3上に半田接合し、ワイヤボンディングを施し、目的とする半導体モジュールを得た。

一方、比較例として、上記高熱伝導性窒化けい素基板10に代えて、厚さ0．6㎜の窒化アルミニウム基板2a，2bを使用した点以外は、実施例3と同様

に処理して比較例に係る半導体モジュールを製造した。 このようにして得た実施例３に係る半導体モジュールおよび比較例の半導体モジュールに対して熱サイクル試験（ＴＣＴ：２３３Ｋ×３０分＋ＲＴ×１０分＋３９８Ｋ×３０分を１サイクルとする）を施し、セラミックス基板における割れの発生割合を測定した。その結果、実施例３の半導体モジュール１ｂは、１００サイクルのＴＣＴ後においてもクラックが発生しなかったのに対して、比較例による半導体モジュールは１００サイクルでセラミックス基板の４～７％にクラックが生じた。

実施例４

高熱伝導性窒化けい素基板として、試料１～５１に係る厚さ０．５㎜の高熱伝導性窒化けい素基板１０を用意すると共に、実施例３と同一形状であり、プレス加工により形成した所定形状の厚さ０．３㎜の銅板３と厚さ０．６㎜の銅板４ｂとを用意した。

そして、高熱伝導性窒化けい素基板１０の両面に、Ｉｎ：Ａｇ：Ｃｕ：Ｔｉ＝１４．０：５９．０：２３．０：４．０組成の活性金属含有ろう材をペースト化したものを塗布し、この塗布層を介して銅板３，４ｂを積層配置した後、窒素ガス雰囲気中にて加熱して接合させ、さらに半導体素子７を銅板３上に半田接合し、ワイヤボンディングを施して目的とする半導体モジュールを得た。

このようにして得た半導体モジュールに対して熱サイクル試験を実施例３と同一条件下で実施したところ、実施例３と同様な良好な結果が得られ、冷熱サイクルに対する信頼性に優れることを確認した。

また上記各実施例に係る半導体モジュールによれば、窒化けい素焼結体が本来的に有する高強度高靭性特性に加えて特に熱伝導率を大幅に改善した高熱伝導性窒化けい素基板１０を使用している。したがって、裏銅板（裏金属板）と、放熱性や構造強度を高めるためのヒートシンク板との両方は必要とせず、構造が簡素化されて製造コストが大幅に削減される。また基板に搭載する半導体素

子７等の発熱部品からの発熱は熱伝導率が高い窒化けい素基板１０を経て迅速に系外に伝達されるため放熱性が極めて良好である。

また、高強度高靭性である高熱伝導率窒化けい素基板１０を使用しているため、モジュールの最大たわみ量を大きく確保することができる。そのため、アッセンブリ工程においてモジュールを機器ケーシング９に取付ねじ６ａによって固定した場合においても、締め付け割れが発生せず、モジュールを用いた半導体装置を高い製造歩留りで安価に量産することが可能になる。

また高熱伝導性窒化けい素基板１０の靭性値が高いため、熱サイクルによって基板１０と金属回路板や金属板４ａ，４ｂとの接合部に割れが発生することが少なく、耐熱サイクル特性が著しく向上し、耐久性および信頼性に優れた半導体装置を提供することができる。

さらに高い熱伝導率を有する窒化けい素基板１０を使用しているため、高出力化および高集積化を指向する半導体素子７を搭載した場合においても、熱抵抗特性の劣化が少なく、優れた放熱性を発揮する。

特に窒化けい素基板自体の機械的強度が優れているため、要求される機械的強度特性を一定とした場合に、他のセラミックス基板を使用した場合と比較して基板厚さをより低減することが可能となる。すなわち従来の半導体モジュールにおいては、セラミックス基板の厚さは０．６～１．０㎜が一般的であったが、本発明で使用する高熱伝導性窒化けい素基板を使用することにより、その厚さを０．１㎜以上０．６㎜未満と薄くした場合においても使用できる。この基板厚さを低減できることから熱抵抗値をより小さくでき、放熱特性をさらに改善することができる。また要求される機械的特性に対して、従来より薄い基板でも十分に対応可能となるため、基板製造コストをより低減することが可能となる。

次に前記試料１～５１として調製した厚さ０．３㎜，０．６㎜の２枚の高熱伝導性窒化けい素基板の両面に、直接接合法または活性金属法を用いて金属板

を一体に接合し多層化することにより、それぞれ窒化けい素回路基板を製造した。

図５は、本発明の一実施例による窒化けい素回路基板の構造を示す断面図である。

図５において、２枚の高熱伝導性窒化けい素基板２１０ａ，２１０ｂは金属板としての銅板２０４を介して一体に接合されており、また高熱伝導性窒化けい素基板２１０ｂの表面には金属板として銅板２０３が接合されている。一方、高熱伝導性窒化けい素基板２１０ａの裏面にも、同様に銅板２０５が接合されており、これらにより窒化けい素回路基板２０９Ａが構成されている。

また、図５に示す窒化けい素回路基板２０９Ａにおける銅板２０３，２０４，２０５は、高熱伝導性窒化けい素基板２１０ａ，２１０ｂに対して直接接合法、いわゆるＤＢＣ法により接合されている。このようなＤＢＣ法を利用する場合の銅板２０３，２０４，２０５としては、タフピッチ銅のような酸素を１００～３０００ppm の割合で含有する銅を用いることが好ましいが、表面を酸化させた無酸素銅を用いることも可能である。なお、銅や銅合金の単板に代えて、高熱伝導性窒化けい素基板２１０ａ，２１０ｂとの接合面が少なくとも銅により構成されている他の金属部材とのクラッド板等を用いることもできる。

高熱伝導性窒化けい素基板２１０ｂの表面側に接合された銅板２０３は、半導体部品等の実装部となるものであり、所望の回路形状にパターニングされている。銅板２０３の所定位置には半導体素子２０７が半田接合されており、半導体素子２０７の電極部と銅板２０３の電極部とはボンディングワイヤ２０８によって電気的に接続されている。また、高熱伝導性窒化けい素基板２１０ａの裏面側に接合された銅板２０５は、接合時における高熱伝導性窒化けい素基板２１０ａの反り等を防止するものであり、中央付近から２分割された状態でほぼ高熱伝導性窒化けい素基板２１０ａの裏面全面に接合、形成されている。裏面側の銅板２０５には、半導体部品等の実装部となる銅板２０３と同じ厚さ

のものを使用してもよいが、銅板２０３の厚さの７０～９０％の厚さの銅板を使用することが好ましい。

ここで、図５に示した窒化けい素回路基板２０９Ａは、２枚の高熱伝導性窒化けい素基板２１０ａ，２１０ｂに銅板２０３，２０４，２０５をＤＢＣ法により接合したものであるが、例えば図６に示すように、銅板２０３，２０４，２０５を活性金属法で２枚の高熱伝導性窒化けい素基板２１０ａ，２１０ｂに接合した窒化けい素回路基板２０９Ｂであってもよい。上記活性金属法は、例えばＴｉ、Ｚｒ、Ｈｆ、Ｎｂ等から選ばれた少なくとも１種の活性金属を含むろう材（以下、活性金属含有ろう材と記す）層２０６を介して、２枚の高熱伝導性窒化けい素基板２１０ａ，２１０ｂと銅板２０３，２０４，２０５とを接合する方法である。

上述したような構造の窒化けい素回路基板２０９Ａ，２０９Ｂにおいては、銅回路板などの金属板２０３，２０４，２０５を直接接合法または活性金属法により接合した２枚の高熱伝導性窒化けい素基板２１０ａ，２１０ｂを、金属板２０３，２０４，２０５を介して多層化している。よって、立体的なアッセンブリが可能となることによって、実装部や回路構成部の面積の増大を図った上で小型化でき、小型高実装が達成できる。

また、銅板などの金属板２０３，２０４，２０５を有する高熱伝導性窒化けい素基板２１０ａ，２１０ｂを多層化することにより、パッケージ等を構成することができるだけでなく、銅板などの金属板を回路構成部として使用するため、従来の多層パッケージに比べて電流ロスが改善でき、また高周波型半導体素子や大電流型半導体素子等への対応が図れる。

次に、実施例の具体例およびその評価結果について述べる。

実施例５

まず、高熱伝導性窒化けい素基板として、前記試料１～５１に係る窒化けい素基板を採用し、空気中で酸化することにより、表面に厚さ４μｍ酸化物層

（SiO_2 層）を有する厚さ０．３㎜および０．６㎜の高熱伝導性窒化けい素基板２１０ａ，２１０ｂを用意すると共に、プレス加工により形成した、タフピッチ銅（酸素含有量：３００ppm ）からなる所定形状の厚さ０．３㎜の銅板２０３，２０４および厚さ０．２５㎜の銅板２０５を用意した。

そして、図５に示したように、高熱伝導性窒化けい素基板２１０ａ，２１０ｂの両面に３枚の銅板２０３，２０４，２０５をそれぞれ直接接触配置し、窒素ガス雰囲気中にて１３４８Ｋの条件で加熱して接合させ、目的とする窒化けい素回路基板２０９Ａを得た。

一方、比較例として、上記高熱伝導性窒化けい素基板２１０ａ，２１０ｂに代えて、図７に示すように厚さ０．８㎜および０．６㎜の窒化アルミニウム基板２０２ａ，２０２ｂを使用した点以外は、実施例５と同様に処理して比較例に係る窒化アルミニウム回路基板を製造した。

このようにして得た実施例５に係る窒化けい素回路基板および比較例の窒化アルミニウム回路基板に対して熱サイクル試験（ＴＣＴ：２３３Ｋ×３０分＋ＲＴ×１０分＋３９８Ｋ×３０分を１サイクルとする）を施し、セラミックス基板における割れの発生割合を測定した。その結果、実施例５の窒化けい素回路基板は、１００サイクルのＴＣＴ後においてもクラックが発生しなかったのに対して、比較例による窒化アルミニウム回路基板は１００サイクルでセラミックス基板の５～９％にクラックが生じた。

実施例６

高熱伝導性窒化けい素基板として、試料１～５１に係る厚さ０．３㎜および０．６㎜の高熱伝導性窒化けい素基板２１０ａ，２１０ｂを用意すると共に、実施例５と同一形状であり、プレス加工により形成した所定形状の厚さ０．３㎜の銅板２０３，２０４と厚さ０．２５㎜の銅板２０５とを用意した。

そして、図６に示すように、高熱伝導性窒化けい素基板２１０ａ，２１０ｂの両面に、Ｉｎ：Ａｇ：Ｃｕ：Ｔｉ＝１４．０：５９．０：２３．０：４．０

組成の活性金属含有ろう材をペースト化したものを塗布し、この塗布層を介して銅板２０３，２０４，２０５を積層配置した後、窒素ガス雰囲気中にて加熱して接合させ、目的とする多層窒化けい素回路基板２０９Ｂを得た。

このようにして得た多層窒化けい素回路基板２０９Ｂに対して熱サイクル試験を実施例５と同一条件下で実施したところ、実施例５と同様な良好な結果が得られ、冷熱サイクルに対する信頼性に優れることを確認した。

また上記各実施例に係る窒化けい素回路基板２０９Ａ，２０９Ｂによれば、窒化けい素焼結体が本来的に有する高強度高靭性特性に加えて特に熱伝導率を大幅に改善した高熱伝導性窒化けい素基板２１０ａ，２１０ｂを使用している。したがって、基板に搭載する半導体素子２０７等の発熱部品からの発熱は熱伝導率が高い窒化けい素基板２１０ａ，２１０ｂを経て迅速に系外に伝達されるため放熱性が極めて良好である。

また、高強度高靭性である高熱伝導率窒化けい素基板２１０ａ，２１０ｂを使用しているため、回路基板の最大たわみ量を大きく確保することができる。そのため、アッセンブリ工程において回路基板の締め付け割れが発生せず、回路基板を用いた半導体装置を高い製造歩留りで安価に量産することが可能になる。

また高熱伝導性窒化けい素基板２１０ａ，２１０ｂの靭性値が高いため、熱サイクルによって基板２１０ａ，２１０ｂと金属回路板や金属板２０３，２０４，２０５との接合部に割れが発生することが少なく、耐熱サイクル特性が著しく向上し、耐久性および信頼性に優れた半導体装置を提供することができる。

さらに高い熱伝導率を有する窒化けい素基板２１０ａ，２１０ｂを使用しているため、高出力化および高集積化を指向する半導体素子２０７を搭載した場合においても、熱抵抗特性の劣化が少なく、優れた放熱性を発揮する。

次に高熱伝導性窒化けい素基板と汎用で安価な基板としてのアルミナ基板とを同一平面上に配置した窒化けい素回路基板の実施例について説明する。

実施例７～９

酸素を１．３重量%、不純物陽イオン元素としてＬｉ，Ｎａ，Ｋ，Ｆｅ，Ｃａ，Ｓｒ，Ｂａ，Ｍｎ，Ｂを合計で０．１５重量%含有し、α相型窒化けい素９７%を含む平均粒径０．５５μmの窒化けい素原料粉末に対して、焼結助剤として平均粒径０．７μmのY_2O_3（酸化イットリウム）粉末５重量%、平均粒径０．５μmのAl_2O_3（アルミナ）粉末１．０重量%を添加し、エチルアルコール中で２４時間湿式混合した後に乾燥して原料粉末混合体を調整した。次に得られた原料粉末混合体に有機バインダを所定量添加して均一に混合した後に、１０００kg／cm^2の成形圧力でプレス成形し、長さ８０mm×幅５０mm×厚さ１～５mmの成形体を多数製作した。次に得られた成形体を７００℃の雰囲気ガス中において２時間脱脂した後に、この脱脂体を窒素ガス雰囲気中７．５気圧にて１９００℃で６時間保持し、緻密化焼結を実施した後に、焼結炉に付設した加熱装置への通電量を制御して焼結炉内温度が１５００℃まで降下するまでの間における焼結体の冷却速度がそれぞれ１００℃／hrとなるように調整して焼結体を徐冷し、さらに得られた各焼結体を研摩加工してそれぞれ熱伝導率ｋが７０W／m・Kであり、厚さが０．４mm，０．６mm，０．８mmである実施例７～９用の窒化けい素（Si_3N_4）基板を調製した。

一方、熱伝導率が６０W／m・K未満の汎用で安価な基板としてそれぞれ熱伝導率が２０W／m・Kであり、厚さが前記Si_3N_4基板と等しい実施例７～９用のアルミナ（Al_2O_3）基板を製造した。

次に図８および図９に示すように、同じ厚さを有するSi_3N_4基板３０２とAl_2O_3基板３０２ａとを同一平面上で組み合せてそれぞれ複合基板３１０を形成した。すなわち半導体素子３０６を搭載する部位にはSi_3N_4基板３０２を配置する一方、その他の部位にはAl_2O_3基板３０２ａを配置して複合基板３１０とした。

次に図８および図９に示すように各窒化けい素基板３０２およびアルミナ基

板３０２ａの表面の回路層を形成する部位および裏面の金属板（銅板）を接合する部位に、３０ｗｔ％Ａｇ－６５％Ｃｕ－５％Ｔｉろう材をスクリーン印刷し乾燥して厚さ２０μｍの活性金属ろう材層３０７ａ，３０７ｂを形成した。この活性金属ろう材層３０７ａ，３０７ｂの所定位置に、タフピッチ電解銅から成る厚さ０．３㎜の銅回路板３０４と厚さ０．２５㎜値の金属板（裏銅板）３０５とを接触配置した状態で、真空中で温度８５０℃で１０分間保持して接合体とした。次に各接合体をエッチング処理することにより、所定回路パターン（回路層）を形成した。さらにSi_3N_4基板３０２上面に接合した銅回路板３０４の中央部に半田層３０８を介して半導体素子３０６を接合して実施例７～９に係る窒化けい素回路基板３０１を多数製造した。

比較例１

実施例７～９で使用したSi_3N_4基板３０２とAl_2O_3基板３０２ａとから成る複合基板３１０に代えて、熱伝導率ｋが１８２Ｗ／ｍ・Ｋであり厚さが０．８㎜の窒化アルミニウム（ＡｌＮ）焼結体のみなら成るセラミックス基板を使用した以外は実施例７～９と同様に活性金属法によって基板表面に銅回路板および金属板を一体に接合して比較例１に係るセラミックス回路基板を製造した。

このようにして調製した実施例７～９および比較例１に係る回路基板の最大たわみ量および抗折強度を測定したところ、実施例７～９に係る窒化けい素回路基板３０１は、従来の窒化アルミニウム基板のみを使用した比較例１の回路基板と比較して２倍以上の最大たわみ量と抗折強度とを有することが判明した。また窒化けい素回路基板の厚さを低減するに伴って、さらにたわみ量および抗折強度が改善されることも確認できた。さらに基板厚さの低減化により、熱抵抗が減少するため、回路基板全体としての放熱特性をさらに改善できることも確認できた。

上記各実施例の窒化けい素回路基板を、図９に示すようにヒートシンク３０

９に接合した後にアッセンブリ工程においてボードに実装したところ、締め付け割れが発生せず、回路基板を用いた半導体装置を高い製造歩留りで量産することができた。

また各回路回路基板について－４５℃から室温（ＲＴ）まで加熱し、引き続き室温から＋１２５℃まで加熱した後に、室温を経て再び－４５℃に冷却するまでを１サイクルとする昇温－降温サイクルを繰り返して付加し、基板部にクラック等が発生するまでのサイクル数を測定する耐熱サイクル試験を実施したところ、実施例７～９の窒化けい素回路基板では１０００サイクル経過後においても、Si_3N_4 基板やAl_2O_3 基板の割れや金属回路板（Ｃｕ回路板）および金属板の剥離が皆無であり、優れた耐熱サイクル特性を示すことが判明した。一方、比較例１の回路基板においては、１００サイクルでクラックが発生し、耐久性が低いことが確認された。

実施例１０

実施例７～９において調製したSi_3N_4 基板であり熱伝導率ｋが７０Ｗ／ｍ・Ｋであり厚さがそれぞれ０．４㎜，０．６㎜，０．８㎜である各Si_3N_4 基板を酸化炉中で温度１３００℃で１２時間加熱することにより、基板の全表面を酸化し、厚さ２μｍの酸化層を形成した。酸化層はSiO_2 皮膜で形成される。

一方、実施例７～９において調製したAl_2O_3 基板であり、熱伝導率ｋが２０Ｗ／ｍ・Ｋであり、厚さがそれぞれ０．４㎜，０．６㎜，０．８㎜である各Al_2O_3 基板を調製した。

次に図１０に示すように同じ厚さを有するSi_3N_4 基板３０２とAl_2O_3 基板３０２ａとを同一平面上で組み合せてそれぞれ複合基板３１０を形成した。すなわち半導体素子３０６を搭載する部位には、Si_3N_4 基板３０２を配置する一方、その他の部位にはAl_2O_3 基板３０２ａを配置して複合基板３１０とした。

次に酸化層３０３を形成したSi_3N_4基板３０２と各Al_2O_3基板３０２ａとを複合化した複合基板３１０の表面側に、厚さ０．３㎜のタフピッチ電解銅から成る銅回路板を接触配置する一方、背面側に厚さ０．２５㎜のタフピッチ銅から成る金属板を裏当て材として接触配置させて積層体とし、この積層体を窒素ガス雰囲気に調整した温度１０７５℃の加熱炉に挿入して１分間加熱することにより、各複合基板３１０の両面に銅回路板または金属板を直接接合し、さらに半導体素子を半田接合して実施例１０に係る窒化けい素回路基板３０１ａをそれぞれ調製した。

各窒化けい素回路基板３０１ａは、図１０に示すようにSi_3N_4基板３０２の全表面にSiO_2から成る酸化層３０３が形成されており、Si_3N_4基板３０２とAl_2O_3基板３０２ａとから成る複合基板３１０の表面側に金属回路板としての銅回路板３０４が直接接合される一方、背面側に裏銅板としての金属板３０５が同様に直接接合され、さらにSi_3N_4基板３０２の表面側に接合した銅回路板３０４の所定位置に半田層３０８を介して半導体素子３０６が一体に接合された構造を有する。なお複合基板３１０の両面に銅回路板３０４または金属板３０５を接合した場合、裏銅板としての金属板３０５は放熱促進および反り防止に寄与するので有効である。

上記のように直接接合法によって回路層を形成した実施例１０に係る窒化けい素回路基板の最大たわみ量は０．８～１．６㎜の範囲であり、また抗折強度は５５０～９００ＭＰａの範囲であり、実施例７～９のように活性金属法で回路層を形成した場合と同等の特性値が得られた。また耐熱サイクル試験において１０００サイクル経過後においてもSi_3N_4基板およびAl_2O_3基板の割れや金属回路板および金属板の剥離が皆無であり、優れた耐熱サイクル特性を示した。

産業上の利用可能性

以上説明したように、本発明の半導体モジュールによれば、窒化けい素焼結体が本来的に有する高強度高靭性特性に加えて特に熱伝導率を大幅に改善した高熱伝導性窒化けい素基板を使用しているため、熱サイクルや組立て時の衝撃力によって基板に割れが発生することが少なく、裏銅板（裏金属板）と、放熱性や構造強度を高めるためのヒートシンク板との両方は必要としない。したがって、半導体モジュールの構造が簡素化されて製造コストが大幅に低減されるとともに、小型化でき高密度実装も可能となる。

また、本発明の窒化けい素回路基板によれば、銅回路板などの金属板を接合した複数の高熱伝導性窒化けい素基板を、金属板を介して多層化している。よって、立体的なアッセンブリが可能となることによって、実装部や回路構成部の面積を増大させるとともに小型化でき、小型高実装が達成できる。

また基板に搭載する半導体素子等の発熱部品からの発熱は、高熱伝導性窒化けい素基板を経て迅速に系外に伝達されるため放熱性が極めて良好である。また、高強度高靭性である窒化けい素基板を使用しているため、モジュールや回路基板の最大たわみ量を大きく確保することができる。そのため、アッセンブリ工程においてモジュールの締め付け割れが発生せず、半導体モジュールを用いた半導体装置を高い製造歩留りで安価に量産することが可能になる。

また、本発明に係る窒化けい素回路基板によれば、窒化けい素焼結体が本来的に有する高強度高靭性特性に加えて特に熱伝導率を大幅に改善した高熱伝導性窒化けい素基板を、特に構造強度および放熱性を要求される部位に配置する一方、その他の部位にアルミナ基板や樹脂基板のように汎用で製造容易で安価な基板を配置し、両基板を同一平面上に配置して形成されているため、製造コストが安価である。また、高強度高靭性である窒化けい素基板を、構造強度が要求される部位に配置することにより、回路基板の最大たわみ量を大きく確保することができる。そのため、アッセンブリ工程において回路基板の締め付け

割れが発生せず、回路基板を用いた半導体装置を高い製造歩留りで安価に量産することが可能になる。

請求の範囲

1．熱伝導率が６０w／m・k以上である高熱伝導性窒化けい素基板と、この高熱伝導性窒化けい素基板に搭載された半導体素子と、この高熱伝導性窒化けい素基板の半導体素子搭載面側に接合された金属回路板と、上記高熱伝導性窒化けい素基板の半導体素子非搭載面側に接合され、かつ機器ケーシングあるいは実装ボードに接合される金属板とを具備することを特徴とする半導体モジュール。

2．機器ケーシングあるいは実装ボードに接合される金属板の厚さが前記金属回路板の厚さ以下であることを特徴とする請求の範囲第１項記載の半導体モジュール。

3．機器ケーシングあるいは実装ボードに接合される金属板の厚さが前記金属回路板の厚さの２倍以上であることを特徴とする請求の範囲第１項記載の半導体モジュール。

4．高熱伝導性窒化けい素基板は、窒化けい素結晶相および粒界相から構成されるとともに粒界相中における結晶化合物相の粒界相全体に対する割合が２０%以上であることを特徴とする請求の範囲第１項記載の半導体モジュール。

5．高熱伝導性窒化けい素基板は、窒化けい素結晶相および粒界相から構成されるとともに粒界相中における結晶化合物相の粒界相全体に対する割合が５０%以上であることを特徴とする請求の範囲第１項記載の半導体モジュール。

6．高熱伝導性窒化けい素基板は、不純物陽イオン元素としてのＬｉ，Ｎａ，Ｋ，Ｆｅ，Ｃａ，Ｓｒ，Ｂａ，Ｍｎ，Ｂを合計で１．０重量%以下含有することを特徴とする請求の範囲第１項記載の半導体モジュール。

7．金属回路板および金属板は、前記高熱伝導性窒化けい素基板に直接接合法により接合されていることを特徴とする請求の範囲第１項記載の半導体モジュール。

8．前記金属回路板および金属板は、前記高熱伝導性窒化けい素基板に活性金属法により接合されていることを特徴とする請求の範囲第１項記載の半導体モジュール。

9．熱伝導率が６０ｗ／ｍ・ｋ以上である複数の高熱伝導高性窒化けい素基板と、この高熱伝導性窒化けい素基板に接合された金属板とを具備し、前記複数の高熱伝導性窒化けい素基板が前記金属板を介して多層化された部分を有することを特徴とする窒化けい素回路基板。

１０．熱伝導率が６０Ｗ／ｍ・Ｋ以上である高熱伝導性窒化けい素基板と熱伝導率が６０Ｗ／ｍ・Ｋ未満である基板とが同一平面上に配置されているとともに、少なくとも上記熱伝導率が６０Ｗ／ｍ・Ｋ以上の高熱伝導性窒化けい素基板に金属回路板が接合されていることを特徴とする窒化けい素回路基板。

１１．高熱伝導性窒化けい素基板は、窒化けい素結晶相および粒界相から構成されるとともに粒界相中における結晶化合物相の粒界相全体に対する割合が２０%以上であることを特徴とする請求の範囲第９項または第１０項記載の窒化けい素回路基板。

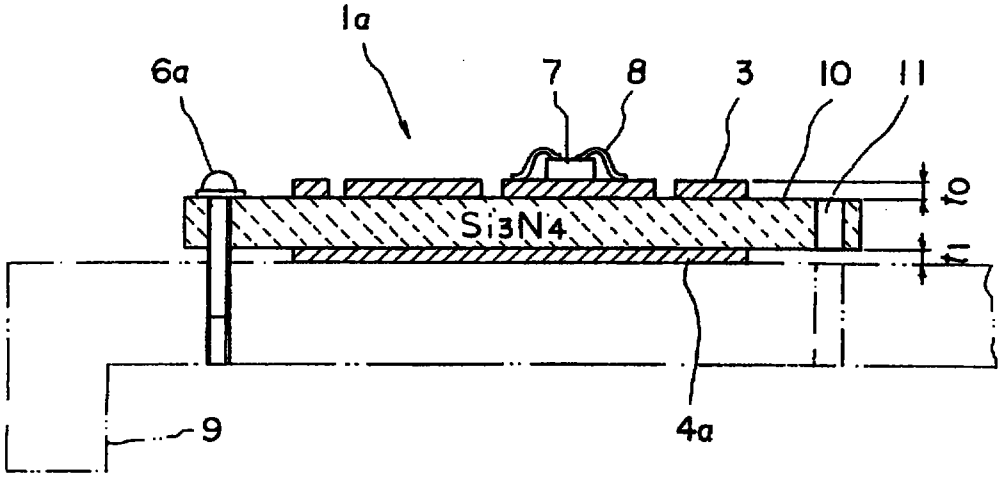
１２．高熱伝導性窒化けい素基板は、窒化けい素結晶相および粒界相から構成されるとともに粒界相中における結晶化合物相の粒界相全体に対する割合が５０％以上であることを特徴とする請求の範囲第９項または第１０項記載の窒化けい素回路基板。

１３．高熱伝導性窒化けい素基板は、不純物陽イオン元素としてのＬｉ，Ｎａ，Ｋ，Ｆｅ，Ｃａ，Ｓｒ，Ｂａ，Ｍｎ，Ｂを合計で１．０重量％以下含有することを特徴とする請求の範囲第９項または第１０項記載の窒化けい素回路基板。

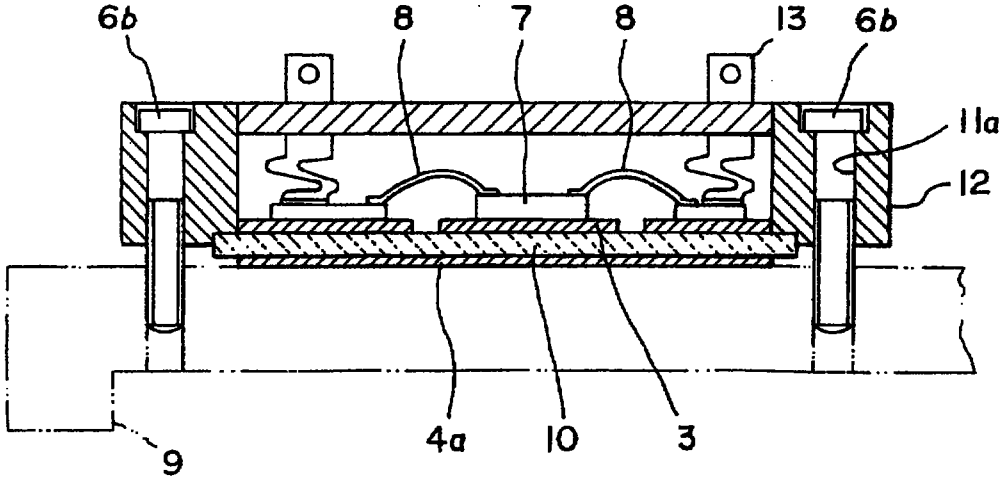
１４．金属板または金属回路基板は、前記高熱伝導性窒化けい素基板に直接接合法により接合されていることを特徴とする請求の範囲第９項または第１０項記載の窒化けい素回路基板。

１５．金属板または金属回路基板は、前記高熱伝導性窒化けい素基板に活性金属法により接合されていることを特徴とする請求の範囲第９項または第１０項記載の窒化けい素回路基板。

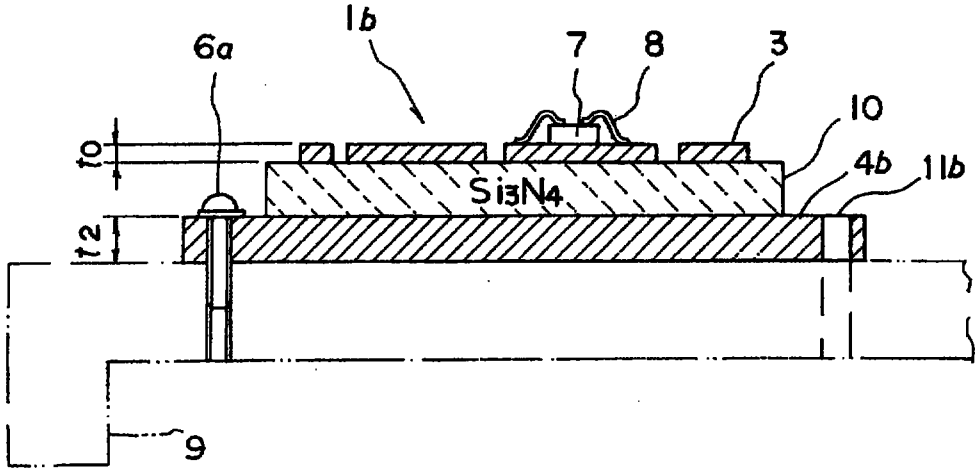
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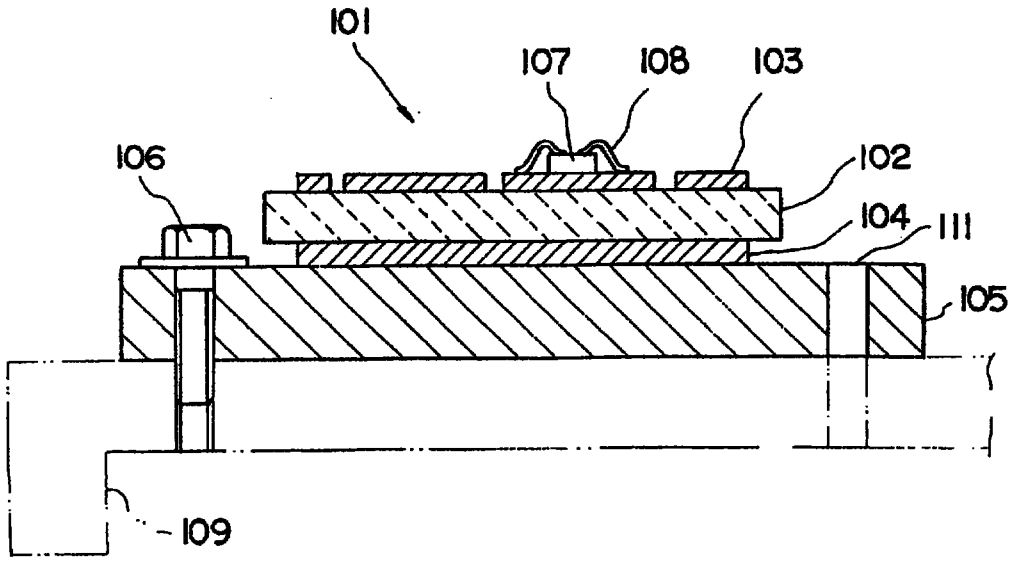
第 1 図



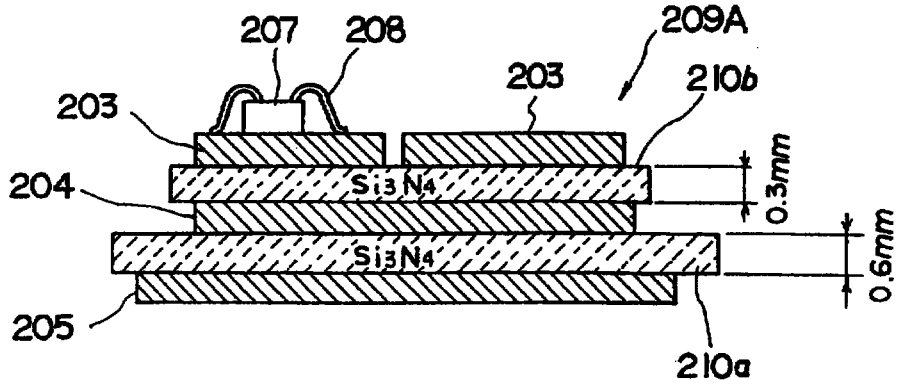
第 2 図


1b
6a
7
8
3
10
4b
11b
t0
t2
Si3N4
9

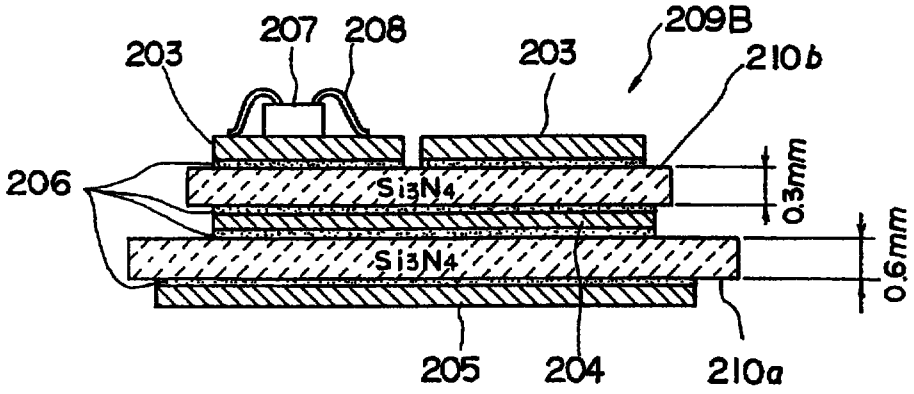
第 3 図


101
107
108
103
106
102
104
111
105
109

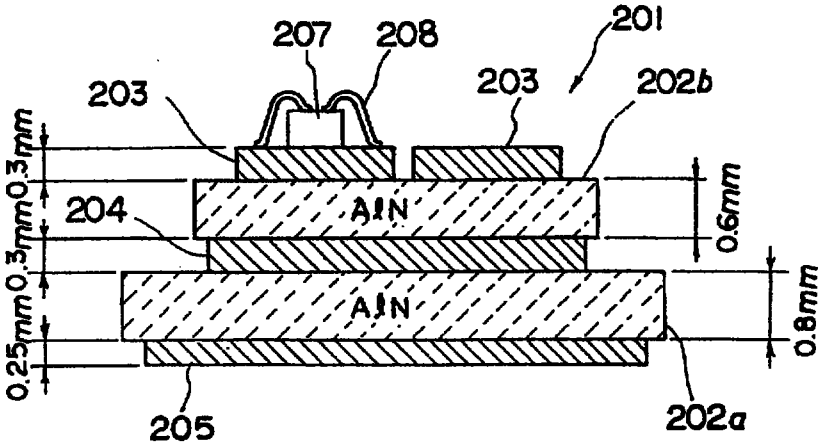
第 4 図


207
208
209A
203
203
210b
204
Si3N4
0.3mm
Si3N4
0.6mm
205
210a

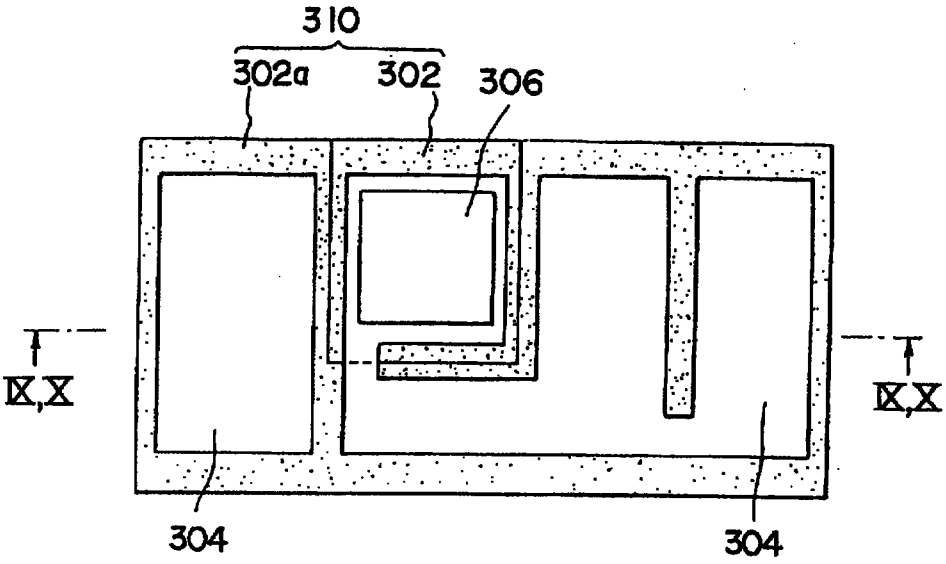
第 5 図


207
208
209B
203
203
210b
206
Si3N4
0.3mm
Si3N4
0.6mm
205
204
210a

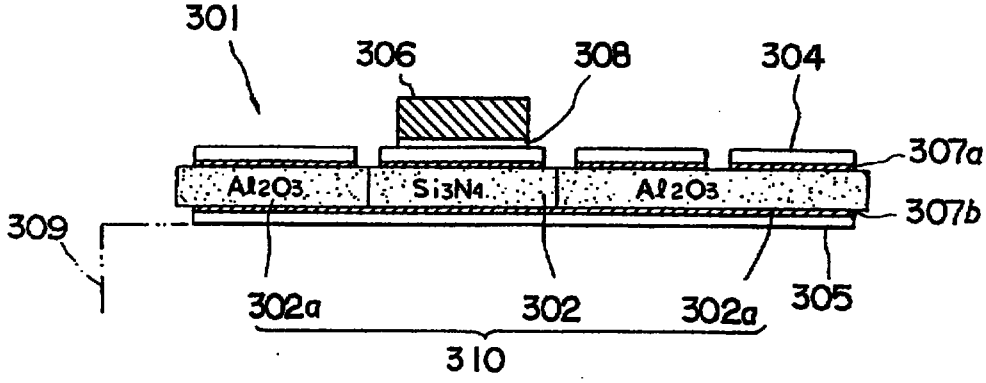
第 6 図


207
208
201
203
203
202b
0.3mm
0.3mm
204
AlN
0.6mm
0.3mm
AlN
0.8mm
0.25mm
205
202a

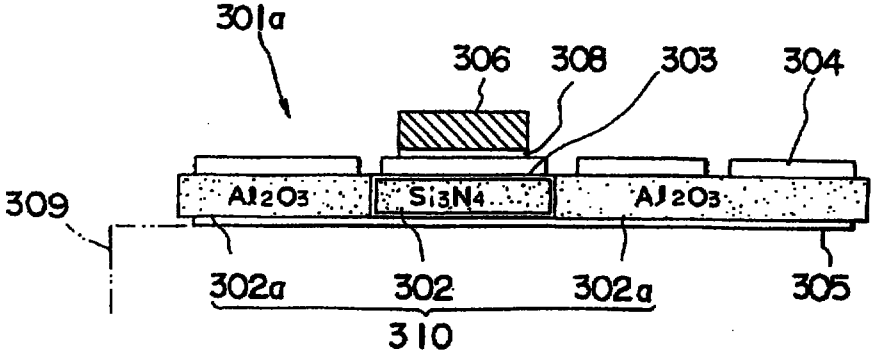
第 7 図


310
302a
302
306
Ⅸ,X
Ⅸ,X
304
304

第 8 図


301
306
308
304
307a
Al2O3
Si3N4
Al2O3
307b
309
302a
302
302a
305
310

第 9 図


301a
306
308
303
304
309
Al2O3
Si3N4
Al2O3
302a
302
302a
305
310

第 10 図

TITLE OF THE INVENTION

SILICON NITRIDE CIRCUIT BOARD AND SEMICONDUCTOR MODULE

BACKGROUND OF THE INVENTION

Field of the Invention

The present invention relates to a silicon nitride circuit board and a semiconductor module which is useful as a semiconductor mounted circuit board, semiconductor package and the like.

Description of the Related Art

Recently, a ceramic circuit board prepared by bonding a metal plate (metal circuit plate) such as a copper plate to a ceramic plate is used as a substrate for mounting of a semiconductor module such as a power transistor module or semiconductor parts dealing relatively high electric power such as a switching current source module and the like.

As a bonding method of a ceramic substrate with a metal plate cut out in given shape in a production process for the ceramic circuit board as described above, a method using an active metal brazing material (active metal method) prepared by adding 1 to 10wt.% of active metal such as Ti, Zr, Hf, Nb and the like to an Ag-Cu brazing material and the like, a so-called direct bonding method (DBC method: direct bonding copper method) in which a ceramic

substrate is directly bonded to a copper plate using tough pitch electrolytic copper containing 100 to 1000 ppm oxygen or copper of which surface is oxidized in a thickness of 1 to 10 μ m as a metal plate, and the like are known.

For example, in the direct bonding method, a 0.3 to 0.5 mm thick copper circuit plate cut out in given shape is first contacted and placed on a 0.6 to 1.0 mm thick ceramic substrate composed of an aluminum oxide (Al_2O_3) sintered material, aluminum nitride (AlN) sintered material and the like, and heated for formation of eutectic crystal liquid phase of $Cu-Cu_2O$ on bonding interface, the surface of the ceramic substrate is wetted with this liquid phase, then, the liquid phase is cooled to be solidified for direct bonding of the ceramic substrate with the copper circuit plates. The ceramic circuit board obtained by using such a direct bonding method has advantages such as possibility of small size and high-density mounting, and the like, since bonding strength between the ceramic substrate with the copper circuit plates is high and it has simple structure in which a metallized layer or brazing material layer is not required. Further, the production process is intended to be shortened.

However, the above-described ceramic circuit board prepared by bonding a metal plate to a ceramic substrate by the direct bonding method, active metal method and the like has a problem that reliability is poor in heat history,

since the metal plate has as large as 0.3 to 0.5 mm thickness for flowing large current. Namely, a ceramic substrate and a metal plate having extremely different heat expansion coefficients are bonded, heat stress derived from the above-described difference in heat expansion coefficient occurs by adding a cooling process and cooling cycle after the bonding. This stress exists in the form of remaining stress distribution of compression and tension on the ceramic substrate side near the bonding portion, and particularly, main stress of the remaining stress acts on ceramic portion adjacent to periphery end of the metal plates. This remaining stress causes cracking on the ceramic substrate, poor withstand voltage, releasing of the metal plate. Further, it exerts a reverse influence that strength of the ceramic substrate is lowered, even if no cracking occurs on the ceramic substrate.

With recent development of high density and highly integrated semiconductor element, miniaturization of a semiconductor module and electronic parts themselves is desired. Under these circumstances, miniaturization of the semiconductor mounted substrate per se is also required.

By the way, an aluminum nitride substrate has a high thermal conductivity and low heat expansion property as compared with other ceramic substrates. However, no aluminum nitride substrate having a sufficient mechanical strength has not been obtained yet. Therefore, when a

slight pressure or impact is imparted to the circuit board in mounting process of the circuit board, the circuit board is easily destroyed, and production yield of a semiconductor apparatus is sometimes reduced steeply.

Therefore, in a conventional semiconductor module, it is essential factor to increase thickness of a ceramic substrate and integrate a reinforcing member with a circuit board. Fig. 4 is a cross-sectional view showing structure of such a conventional semiconductor module 101. The semiconductor module 101 shown in Fig. 4 has a large thickness, and is formed by bonding metal circuit plates 103 to a front surface of a ceramic substrate 102 made of an AlN sintered body having a high thermal conductivity, and at the same time by bonding a metal plate 104 as a backing copper plate to the rear surface of the ceramic substrate 102. Further, a semiconductor element 107 is mounted on a predetermined position of the metal circuit plate 103 by solder bonding, and an electrode portion of the metal circuit plate 103 and the semiconductor element 107 are electrically connected by a bonding wire 108.

The ceramic circuit board constructed as described above is integrated to the surface of a heat sink plate 105 made of, for example, copper by solder bonding, and a semiconductor module 101 as shown in Fig. 4 is formed. This semiconductor module 101 is fixed on an apparatus casing 109, a heat releasing fin or a mounting board by securing

with an attaching screw 106.

However, the above-described conventional semiconductor module 101 or ceramic circuit board has problems that size becomes large when constructed as a semiconductor module and it is difficult to produce a small size module, and production cost for a ceramic substrate increases. In addition, since a heat sink plate which improves heat releasing property and prevents cracking of the ceramic substrate is required, and further, since it is necessary to use a ceramic substrate having a large thickness for enhancing resistance against cracking. Further, since thickness of the substrate increases, there is a problem that heat resistance increases and excellent heat releasing property as expected cannot be obtained even if an AlN substrate having a high thermal conductivity is used.

The present invention has been accomplished to cope with such problems, and a first object thereof is to provide a semiconductor module which does not require both a rear copper plate (rear metal plate) and a heat sink plate, of which structure is simple and can be miniaturized, and of which heat releasing property and heat cycle durability are improved.

On the other hand, with recent development of high density and highly integrated semiconductor element, miniaturization of a semiconductor module and electronic

parts themselves is desired, and for high densely mounting, an enlargement of area for mounting part and circuit constituting part is desired.

However, in the conventional ceramic circuit board, since one main surface of a ceramic substrate is only used as a mounting surface, it is necessary to enlarge the ceramic substrate itself for increasing mounting part and circuit constituting part. When the ceramic substrate is enlarged, however, there may be posed problems that the ceramic substrate tends to bend in bonding process for bonding the copper circuit plates and the like. Further, simple enlargement of the ceramic substrate goes against the requirement for miniaturization of a mounting substrate and the electronic parts themselves.

As described above, in the conventional ceramic circuit board, the ceramic substrate should be enlarged for increasing the area of mounting part and the circuit constitutional part, and this invites poor bonding of the copper circuit plates and goes against requirement for miniaturization of the electronic parts. Further, with diversification of the semiconductor element, various properties are required for a semiconductor mounting substrate and semiconductor package, and it is desired to satisfy the various requirements.

On the other hand, high densely integration, high power performance and enlargement of a semiconductor

element have been developed, and circuit board structure which can effectively dissipate heat generated from the semiconductor element outside of the system and circuit board structure having a high strength which can endure heat stress are technically required. Then, a silicon nitride (Si_3N_4) substrate having higher strength than that of a conventional alumina (Al_2O_3) substrate has been tried to be used as a ceramic substrate. However, since the Si_3N_4 substrate has a remarkably lower thermal conductivity as compared with an aluminum nitride substrate and the like though it has excellent mechanical strength such as toughness and the like. Therefore, the Si_3N_4 substrate is not practically used as a constitutional material of a circuit board for a semiconductor to which heat releasing property is particularly required.

On the other hand, the aluminum nitride (AlN) substrate has a higher thermal conductivity and lower heat expansion property as compared with other ceramic substrates, no aluminum nitride substrate having satisfactory mechanical strength has not been obtained yet. Therefore, when slight pressure or impact is imparted to AlN substrate in mounting process of a circuit board, the circuit board is easily destroyed, and production yield of a semiconductor device is sometimes reduced steeply.

Therefore, in the conventional ceramic circuit board, it is essential requirement to increase thickness of

the ceramic substrate. Fig. 7 is a cross-sectional view showing structure of such a conventional ceramic circuit board 201. The ceramic circuit board 201 as shown in Fig. 7 has a large thickness, and is formed by bonding two ceramic substrates 202a, 202b made of an AlN sintered body having a high thermal conductivity through a copper plate 204 as a metal circuit plate, by bonding a copper plate 203 to the upper surface of the ceramic substrate 202b, and by simultaneously bonding a metal plate 205 as a rear copper plate to the rear surface of the ceramic substrate 202a for integration. At a predetermined portion of the copper plate 203, a semiconductor element 207 is mounted by solder bonding, and an electrode portion of the copper plate 203 and the semiconductor element 207 are electrically connected by a bonding wire 208.

As described above, the above-described conventional ceramic (AlN) circuit board 201 has problems that the size is large when constructed as a semiconductor module and it is difficult to produce a small size module, and production cost for a ceramic substrate increases, since it is necessary to use ceramic substrates 202a, 202b each having a large thickness for improving the resistance against cracking. Further, since thickness of the substrate increases, there is a problem that heat resistance increases and excellent heat releasing property as expected cannot be obtained even if an AlN substrate having a high

thermal conductivity is used.

The present invention has been accomplished to cope with such problems, and a second object thereof is to provide a silicon nitride circuit board which has an excellent heat releasing property, can enlarge area of mounting part and circuit constituting parts and can be miniaturized, and further, which has an improved heat cycle durability and excellent reliability.

Disclosure of the Invention

The semiconductor module of the present invention comprises a high thermal conductive silicon nitride substrate having a thermal conductivity of 60 w/m· k or more, a semiconductor element mounted on this high thermal conductive silicon nitride substrate, metal circuit plates that are bonded to the high thermal conductive silicon nitride substrate at a side to which a semiconductor element is mounted, and single metal plate which is bonded to the high thermal conductive silicon nitride substrate at a side to which the semiconductor element is not mounted and is bonded to an apparatus casing or a mounting board.

As a preferable embodiment of the above-described semiconductor module of the present invention, there are listed an embodiment in which the thickness of the metal plate which is bonded to the apparatus casing or the mounting board is less than that of the above-described

metal circuit plate, an embodiment in which a thickness of the metal plate which is bonded to the apparatus casing or the mounting board is more than two times of that of the above-described metal circuit plate, an embodiment in which the above-described metal plate is bonded to the above-described high thermal conductive silicon nitride substrate by a direct bonding method, and further, an embodiment in which the above-described metal plate is bonded to the above-described high thermal conductive silicon nitride substrate by an active metal brazing method.

The silicon nitride circuit board of the present invention comprises a plurality of high thermal conductive silicon nitride substrates each having a thermal conductivity of 60 w/m· k or more and a metal plate which is bonded to this highly thermal conductive silicon nitride substrate, and has a part in which a plurality of the high thermal conductive silicon nitride substrates form a plural-layered structure through the metal plate.

As a more preferable embodiment of the above-described silicon nitride circuit board, there can be provided an embodiment in which the above-described metal plate is bonded to the high thermal conductive silicon nitride substrate by a direct bonding method, and an embodiment in which the metal plate is bonded to the high thermal conductive silicon nitride substrate by an active metal brazing method.

Further, in the silicon nitride circuit board of the present invention, a high thermal conductive silicon nitride substrate having a thermal conductivity of 60 w/m· k or more and a substrate having a thermal conductivity of less than 60 w/m· k are provided on the same plane, and metal circuit plates are bonded to at least the high thermal conductive silicon nitride substrate having a thermal conductivity of 60 w/m· k or more.

As the substrate having a thermal conductivity of less than 60 w/m· k, an alumina (Al_2O_3) substrate, resin substrate and the like can be used.

A metal plate may advantageously bonded to the high thermal conductive silicon nitride substrate having a thermal conductivity of 60 w/m· k or more and a cheap substrate for general use having a thermal conductivity of less than 60 w/m· k which can be easily produced through an oxidized layer formed on rear surfaces of the respective substrate. Further, a metal plate may also be directly bonded to both the high thermal conductive silicon nitride substrate and the cheap substrate for general use through the oxidized layer so that the metal plate extends to both substrate.

Namely, according to the present invention, it becomes possible to obtain a cheap circuit board which can be easily produced with maintaining an excellent strength and heat releasing property. Namely, a complex silicon

nitride circuit board can be obtained by combining a silicon nitride substrate excellent in thermal conductivity, strength and toughness with a cheap substrate for general use which can be easily produced.

Arrangement of the above-described high thermal conductive silicon nitride substrate and the substrate having a thermal conductivity of less than 60 w/m· k is roughly classified into the following three types. Namely, there are three embodiments; an embodiment in which the both substrates are placed so as to be adjacent to each other on the same plane; an embodiment in which the both substrates are laminated so as to form a sandwich-structure, and an embodiment in which a plurality of high thermal conductive silicon nitride substrates are placed on a surface of an alumina substrate or a resin substrate. These embodiments may be combined in accordance with the required properties.

For example, an excellent heat releasing property of whole circuit board can be secured by arranging the high thermal conductive silicon nitride substrate to a portion on which a semiconductor element as a highly heat generating part is mounted. Further, when a surface portion of the circuit board to which mechanical pressure, mechanical stress and the like are directly applied is constructed by the silicon nitride substrate having a high strength and a high toughness, it becomes possible to

suppress cracking due to the fastening operation for fastening the circuit board in an assembly process, a crack formation under the heat cycled condition, and the like.

Further, in the above-described silicon nitride circuit board, metal circuit plates may be bonded to the high thermal conductive silicon nitride substrate and the cheap substrate through a metal bonding layer containing at least one active metal selected from Ti, Zr, Hf and Nb, the metal bonding layer being formed on the surface of the high thermal conductive silicon nitride substrate and the cheap substrate for general use which can be easily produced.

Further, a metal plate may also be bonded through a metal bonding layer formed on the surface of the above-described high thermal conductive silicon nitride substrate and the cheap substrate for general use which can be easily produced. The thickness of the metal circuit plate may advantageously be larger than that of the metal plate. Further, the metal plate may be bonded through a metal bonding layer to both the high thermal conductive silicon nitride substrate and the cheap substrate for general use so that the metal plate ranges to both substrate. Further, at least one metal circuit plate may advantageously be bonded through a metal bonding layer to both the high thermal conductive silicon nitride substrate and the cheap substrate for general use so that the metal circuit plates range to both substrates.

The high thermal conductive silicon nitride substrate to be used in the present invention may be constructed so as to contain a rare earth element in an amount of 1.0 to 17.5% by weight in terms of oxide thereof, and impurity cationic elements of Li, Na, K, Fe, Ca, Sr, Ba, Mn and B in a total amount of 1.0% by weight or less, preferably 0.3% by weight or less (including 0% by weight as a detection limit).

Here, as a matter of course, the above-described content range of 1.0 to 17.5% by weight of the rare earth oxide includes 1.0% by weight which is a lower limit of the content and 17.5% by weight which is an upper limit of the content. This is natural as mathematical expression, and also applied to the content ranges of other components.

In another aspect of this invention, the high thermal conductive silicon nitride substrate can be formed of a silicon nitride sintered body which contains a rare earth element in an amount of 1.0 to 17.5% by weight in terms of oxide thereof, and consists of silicon nitride crystal phase and grain boundary phase wherein a proportion of the crystalline compound phase in the grain boundary phase is 20% or more, preferably 50% or more based on the whole grain boundary phase.

It is particularly preferable to use a lanthanoid element as the above-described rare earth element for improving a thermal conductivity.

The high thermal conductive silicon nitride substrate used in the present invention may preferably contain at least one element selected from Ti, Zr, Hf, V, Nb, Ta, Cr, Mo and W in an amount of 0.1 to 3.0% by weight in terms of oxide thereof. This at least one element selected from Ti, Zr, Hf, V, Nb, Ta, Cr, Mo and W can be contained by being added to a silicon nitride powder as an oxide, carbide, nitride, silicide or boride.

The high thermal conductive silicon nitride substrate used in the present invention can be produced by a method in which a molded compact is prepared by molding a raw material mixture prepared by adding a rare earth element in an amount of 1.0 to 17.5% by weight in terms of oxide thereof to a silicon nitride powder having an average particle size of 1.0μm or less which contains oxygen in an amount of 1.7% by weight or less, impurity cationic elements, Li, Na, K, Fe, Ca, Sr, Ba, Mn and B in a total amount of 1.0% by weight or less, preferably 0.3% by weight or less, andα-phase type silicon nitride in an amount of 90% by weight or more, the resulted molded compact is degreased, then, is sintered under a pressured atmosphere of 1800 to 2100 ℃, and is gradually cooled at a cooling rate of 100 ℃/hour or less such that the sintering temperature decreases to a temperature at which a liquid phase formed from the above-described rare earth element in sintering is solidified.

According to the above-described production method, grain boundary phase containing a rare earth element and the like in silicon nitride crystal structure, and there can be obtained a silicon nitride substrate excellent in both mechanical property and thermal conductive property and having a porosity of 2.5% or less, a thermal conductivity of 60 w/m· k or more and a three point bending strength at room temperature of 650 MPa or more.

In the high thermal conductive silicon nitride substrate used in the present invention, the content of the above-described impurity cation elements can never become completely 0% by weight in mathematical sense. Therefore, the content of the impurity ion element prescribed in the present invention substantially includes 0% by weight as a detection limit irrespective of detection limit level.

Further, a silicon nitride substrate having a high density can be produced by using a silicon nitride raw material powder containing 90% by weight or more of α-phase type silicon nitride excellent in sintering property as compared with β-phase type silicon nitride.

As the rare earth element to be added to the silicon nitride raw material powder as a sintering aid, oxides of Ho, Er, Yb, Y, La, Sc, Pr, Ce, Nd, Dy, Sm, Gd and the like or substances which are converted to these oxide by sintering operation may be contained alone or in

combination of two or more. Particularly, holmium oxide (Ho_2O_3) and erbium oxide (Er_2O_3) are preferred.

Especially, by using lanthanoid series elements of Ho, Er or Yb as a rare earth element, sintering property is improved or high thermal conductivity is realized, and a sintered body which is fully densified can be obtained even in a low temperature range around 1850℃. Therefore, there can be also obtained effects of that apparatus cost and running cost of a sintering apparatus can be reduced. This sintering aid reacts with a silicon nitride raw material powder to form a liquid phase, and functions as a sintering accelerator.

The addition amount of the above-described sintering aid shall be in the range from 1.0 to 17.5 wt.% based on a raw material powder in terms of oxide thereof. When this addition amount is less than 1.0% by weight, compactness (densification) of the sintered body is insufficient, and particularly when a rare earth element is a high atomic number element such as lanthanoid series element, a sintered body having a relatively low strength and relatively low thermal conductivity is formed. On the other hand, when the addition amount is over 17.5% by weight, excess amount of grain boundary phase is disadvantageously formed, and thermal conductivity and strength begin to lower. Therefore, the above-described content range is prescribed. Particularly, because of the

same reasons, the content range is desirably from 4 to 15% by weight.

The oxide, carbide, nitride, silicide or boride of Ti, Zr, Hf, V, Nb, Ta, Cr, Mo and W used as other selective additive component in the above-described production method promotes the function of the sintering accelerator of a rare earth element, and performs function for strengthening dispersion in the crystal structure, and improves a mechanical strength of the Si_3N_4 sintered body. In particular, compounds of Hf and Ti are preferable. When the addition amount of these compounds is less than 0.1% by weight, the addition effect is insufficient. On the other hand, when the amount is excess over 3.0% by weight, thermal conductivity, mechanical strength and electric breakdown strength are lowered. Therefore, the addition amount is shall be set to the range from 0.1 to 3.0% by weight. It is particularly desirable that the range shall be set to a range from 0.2 to 2% by weight.

Further, the compounds of Ti, Zr, Hf and the like also function as a shading agent or light shielding agent which colors a silicon nitride sintered body blackish to impart opacity. Therefore, when a circuit board on which an integrated circuit and the like which is liable to cause malfunction by a light is mounted is produced, it is desirable to appropriately add the above-described compounds such as Ti and the like and make a silicon

nitride substrate excellent in shading property.

The sintered body is so produced that the porosity thereof is not more than 2.5% since it exerts an large influence on thermal conductivity and strength. When the porosity is over 2.5%, the thermal conductivity is disturbed, and the thermal conductivity of the sintered body is lowered, and the strength of the sintered body is also lowered.

Further, the silicon nitride sintered body is constituted from silicon nitride crystal phase and grain boundary phase, and a ratio or proportion of the crystalline compound phase in the grain boundary phase exerts an large influence on the thermal conductivity of the sintered body. Therefore, in the high thermal conductive silicon nitride substrate used in the present invention, it is necessary that the proportion of the crystalline compound phase is 20% or more, and more preferably, it is desirable that the proportion in the grain boundary phase is 50% or more.

Further, for obtaining the high thermal conductive silicon nitride substrate having a porosity of not more than 2.5% and a proportion of the crystal phase in the grain boundary phase formed in the silicon nitride crystal structure of 20% or more as described above, it is important to sinter a silicon nitride molded article under a pressured atmosphere for about 2 to 10 hours at 1800 to

2100℃ , and to gradually cool the sintered body such that a cooling rate of the sintered body immediately after the sintering operation is completed is set to be 100 ℃ /hour or less.

When the sintering temperature is less than 1800℃ , compactness or density of the sintered body is insufficient, and the porosity becomes 2.5% by volume or more, and consequently the mechanical strength and the thermal conductivity of the sintered body are lowered together. On the other hand, when the sintering temperature is over 2100℃ , the silicon nitride component itself tends to be vaporized and decomposed. In particular, when not pressured-sintering but ordinary pressure-sintering is conducted, decomposition and vaporization of the silicon nitride initiate from a temperature of around 1800℃ .

The cooling rate of the sintered body immediately after the completion of the sintering operation is an important controlling factor for crystallizing the grain boundary phase, and when quick cooling in which the cooling rate is over 100℃ per hour is conducted, the grains boundary phase of the sintered body structure becomes non-crystalline (amorphous, glass phase), and the proportion of liquid phase formed as crystal phase in the sintered body becomes less than 20% in the grain boundary phase, and consequently, both strength and thermal conductivity are decreased.

It is sufficient that the above-described temperature range in which the cooling temperature should be strictly controlled is from a predetermined sintering temperature (1800 to 2100 ℃) to a temperature at which liquid phase formed by the reaction of the sintering aid is solidified. The liquid phase solidifying temperature when the sintering aid as described above is used is approximately from 1600 to 1500 ℃. When the cooling rate of the sintered body from at least the sintering temperature to the above-described liquid phase solidifying temperature is controlled to be 100 ℃/hour or less, preferably 50 ℃/hour or less, and more preferably 25 ℃/hour or less, 20% or more, particularly preferably 50% or more of the grain boundary phase becomes a crystal phase. As a result, a sintered body excellent in both thermal conductivity and mechanical strength can be obtained.

The high thermal conductive silicon nitride substrate used in the present invention is produced, for example, through the following processes. Namely, a predetermined amount of a sintering aid, a necessary additive such as an organic binder and the like and optionally Al_2O_3, AlN, Ti compound and the like are added to a fine silicon nitride powder which has the above-described given fine particle size and contains a small amount of impurities thereby to prepare a raw material mixture. Then, the resulted raw material mixture

is molded to obtain a molded body having a predetermined shape. As a method of molding the raw material mixture, a metal-mold (die) pressing method for general use, a sheet molding method such as a doctor blade method, and the like can be applied. Following the above-described molding operation, the molded body is preheated for 1 to 2 hours at 600 to 800 ℃ in a non-oxidizing atmosphere or at 400 to 500 ℃ in air, and the previously added organic binder component is fully removed and the molded body is degreased. Then, the degreased molded body is sintered under a pressured atmosphere of an inert gas such as a hydrogen gas and argon gas at a temperature of 1800 to 2100 ℃ for a predetermined period of time.

The silicon nitride substrate produced by the above-described production method has a porosity of 2.5% or less, a thermal conductivity of 60 w/m· k (at 25℃) or more and a three point bending strength at ordinary temperature of 650 MPa or more, therefore the substrate is excellent also in mechanical properties.

The present invention does not include a silicon nitride substrate having a thermal conductivity of whole sintered body of 60 w/m· k or more obtained by adding high thermal conductive SiC and the like to a low thermal conductive silicon nitride. However, it is needless to say that the present invention includes a silicon nitride-based substrate obtained by combining a high thermal conductive

SiC and the like with a silicon nitride sintered body having a thermal conductivity of 60 w/m· K or more.

The semiconductor module of the present invention is produced by integrally bonding a metal circuit plate and a metal plate having electric conductivity onto a front surface and a rear surface of the highly thermal conductive silicon nitride substrate produced as described above, respectively, using the above-described direct bonding method or the active metal brazing method.

In the semiconductor module of the present invention, since a high thermal conductive silicon nitride substrate having a sharply improved thermal conductivity in addition to a high strength and high toughness property originally owned by a silicon nitride sintered body is used as a ceramic substrate, cracking to be caused by the impacts applied in heat cycles and assembling operation of the modules seldom occurs on the substrate, and the module does not need both a rear copper plate (backing metal plate) and a heat sink plate for enhancing heat releasing property and structural strength. Therefore, the structure of the semiconductor module can be simplified and the production cost is steeply reduced, and further, the module can be miniaturized and high density mounting becomes possible.

Further, heat generated from a heat generating part such as a semiconductor element and the like mounted

on the substrate is transmitted outside of the system quickly through the high thermal conductive silicon nitride substrate, therefore, heat releasing property of the module is extremely excellent. Further, since the silicon nitride substrate having a high strength and a high toughness is used, maximum deflecting of the module can be secured at a high level. Therefore, cracking due to fastening of the module in the assembly process does not occur, and a semiconductor apparatus using the semiconductor module can be cheaply produced in a large amount with a high production yield.

Since toughness of the high thermal conductive silicon nitride substrate is high, cracking seldom occurs on the connected portion between the substrate and the metal plate even if the heat cycles are applied, the heat cycle resistance property is remarkably improved, and a semiconductor apparatus excellent in durability and reliability can be provided.

Further, since the silicon nitride substrate having a high thermal conductivity is used, degradation in heat resistance property is small and excellent heat releasing property is demonstrated even if a semiconductor element directing to high output and high integration is mounted.

In particular, since the mechanical strength of the high thermal conductive silicon nitride substrate

itself is excellent, when required mechanical strength properties are set to be constant, the thickness of the substrate can be reduced as compared with the case in which other ceramic substrate is used. Since the thickness of the substrate can be reduced as described above, the heat resistance can be more reduced, and the heat releasing property can be further improved. Further, since it is possible to cope with the required mechanical properties even with a substrate thinner than a conventional substrate, production cost of the substrate can be reduced.

Further, when only a conventional high thermal conductive aluminum nitride (AlN) substrate is used as a constituting material of a circuit board, it is necessary to increase the thickness of the aluminum nitride substrate for securing a certain degree of mechanical strength. However, in the semiconductor module and circuit board of the present invention, high heat releasing property is secured and high strength property is secured simultaneously mainly by a high thermal conductive silicon nitride substrate having a small thickness. Therefore whole module and whole circuit board can be formed in a small size.

On the other hand, the silicon nitride circuit board of the present invention is produced by integrally bonding a metal plate having electric conductivity to a portion between a plurality of the high thermal conductive

silicon nitride substrates or to the front surface and/or optionally on the rear surface of the high thermal conductive silicon nitride substrates produced as described above by using the direct bonding method or the active metal brazing method.

Namely, in the silicon nitride circuit board of the present invention, a plurality of high thermal conductive silicon nitride substrates to which metal plates such as copper circuit plates and the like are bonded by using the direct bonding method or the active metal brazing method are plural-layered through the metal plate. Therefore, due to this possibility of three-dimensional assembly, the circuit board can be miniaturized with enlarging area of mounting portion and circuit constituting portions, and a small-sized arrangement and a high-density mounting can be accomplished.

Further, by preparing a plural-layered structure of the high thermal conductive silicon nitride substrates having a metal plate such as a copper plate, a package and the like can be produced. In addition, since a metal plate such as a copper plate is used as circuit constituting portions, current loss can be decreased as compared with a conventional plural-layered package, and the structure of the present invention can be applied to a high frequency type semiconductor element and a heavy current type semiconductor element.

In particular, since a high thermal conductive silicon nitride substrate having a sharply improved thermal conductivity in addition to a high strength and a high toughness property originally owned by a silicon nitride sintered body is used as a ceramic substrate, heat generated from a heat generating part such as a semiconductor element and the like mounted on the substrate is transmitted outside of the system quickly via the high thermal conductive silicon nitride substrate. Therefore, heat releasing property of the module becomes extremely excellent. Further, since the silicon nitride substrate having a high strength and a high toughness is used, a maximum deflecting amount of the module can be secured at a high level. Therefore, cracking due to fastening of the circuit board in the assembly process does not occur, and a semiconductor apparatus using the circuit board can be cheaply mass-produced in a large scale with a high production yield.

Further, in the silicon nitride circuit board of the present invention in which a silicon nitride substrate having a thermal conductivity of 60 w/m· k or more and a substrate having a thermal conductivity of less than 60 w/m· k are combined, the thickness of the high thermal conductive silicon nitride substrate can be variously changed according to required properties when used as a circuit substrate, and may be advantageously set to a

predetermined value not more than 2-fold of the thickness of the circuit layer (circuit plate). When the thickness of the silicon nitride substrate is over 2-fold of the thickness of the circuit layer, the thickness of whole circuit board increases and the heat resistance increases. A concrete thickness of the silicon nitride substrate is in the range from 0.25 to 1.2 mm. Particularly, if the thickness of the silicon nitride substrate is set to a value not more than 0.8 mm, the thickness of whole circuit board can be reduced, a difference in heat resistance between the upper and lower surfaces of the circuit board can be more effectively reduced, and heat releasing property of whole the circuit board can be more improved.

On the other hand, the substrate having a thermal conductivity of less than 60 w/m· k used in the present invention is not particularly restricted. However, in view of low production cost, cheap substrates for general use such as an aluminum (Al_2O_3) substrate, resin substrate and the like can be particularly suitably used.

In the present invention, the two kinds of substrates i.e., the high thermal conductive silicon nitride substrate having a thermal conductivity of 60 w/m · k or more and the cheap substrate for general use having a thermal conductivity of less than 60 w/m· k are selectively used according to the required properties for the circuit board. Namely, a complex substrate is formed by

placing the above-described high thermal conductive silicon nitride substrate on a part to which a structural strength and heat releasing property are required, and on the other hand, the cheap substrate for general use which can be easily produced is placed on other parts of the same plane.

The silicon nitride circuit board of the present invention is produced by bonding metal circuit plates having electric conductivity to the surface of the complex substrate produced as described above, and further, by mounting a semiconductor element through this metal circuit plate.

Further, it is preferable to integrally bond single metal plate to the rear surface, i.e., the surface opposing to the metal circuit plates-bonded surface of the complex substrate in which the high thermal conductive silicon nitride substrate and the cheap substrate for general use are combined on the same plane as described above. The metal plate is made of the same material as that of the metal circuit plates. By integrally bonding this metal plate, the circuit board is easily bonded to a heat releasing part such as a heat sink and the like. In addition, a deflection (warpage) and a deformation of the circuit board derived from a difference in heat expansion between the complex substrate and the metal circuit plates can be effectively prevented.

In particular, when the thickness of the metal

circuit plates that are relatively sparsely formed is set to a value larger than that of the metal plate which is densely formed, amounts of the metals placed on both the front and rear surfaces of the complex substrate can be made equivalent, a difference in heat expansion between the front and rear surfaces of the complex substrate can be decreased. As a result, a deflection and deformation of the complex circuit board can be effectively prevented.

Further, when at least one metal circuit plate or at least one metal plate is integrally bonded to both the high thermal conductive silicon nitride substrate and the cheap substrate for general use, the silicon nitride substrate and the cheap substrate for general use placed on the same surface are bonded to each other, and integrity of the complex silicon nitride circuit board can be enhanced.

The bonding method of the metal circuit plates and the metal plate is not particularly restricted, and a direct bonding method and an active metal brazing method to be explained below can be applied.

The direct bonding method is a method in which an oxide layer having a thickness of about 0.5 to 10 μm is formed on the surface of a complex substrate comprising a silicon nitride substrate and a cheap substrate for general use, and metal circuit plates and metal plate which are used as a circuit layer are directly bonded to the above-described complex substrate through this oxide

layer. The metal circuit plates and the metal plate are directly bonded to the surface of the complex substrate without using a bonding agent such as brazing material. Namely, an eutectic compound composed of a component of the metal circuit plates with a component of the substrate is generated by heating, and the both members are bonded to each other using this eutectic compound as a bonding agent.

This direct bonding method can be applied only to oxide type ceramic such as Al_2O_3 and the like, and if this method is applied to non-oxide type ceramic such as a silicon nitride substrate, aluminum nitride substrate and the like, a sufficient bonding strength of the metal circuit plate can not be obtained since wetting property against the substrate is low.

Therefore, in order to improve this wetting property against the substrate, it is necessary to previously form an oxide layer on the surface of the silicon nitride substrate or the aluminum nitride substrate. This oxide layer is formed by heating the above-described silicon nitride substrate or the aluminum nitride substrate at a temperature of 1000 to 1400℃ for 0.1 to 48 hours in an oxidizing atmosphere such as air and the like. When the thickness of this oxide layer is less than 0.5μm, the above-described effect for improving the wetting property is weak, and even if the thickness is over 10μm, the improving effect is saturated, and further,

thermal conductivity tends to decrease. Therefore, the thickness of the oxide layer is set to a range from 0.5 to 10μ m, more preferably to a range from 1 to 5 μ m.

The oxide layer of the Si_3N_4 substrate was originally made of only SiO_2 which is an oxidized material of the Si_3N_4 substrate component. However, an oxide of the rare earth element which had been added to the Si_3N_4 substrate as a sintering aid diffuses and migrates toward a direction for the oxide layer when the bonding operation of the metal circuit plate by heating is conducted. As a result, a structure in which the rare earth oxide is condensed in the oxide layer is formed. For example, when Y_2O_3 is used as the sintering aid, the oxide layer after the bonding operation by heating is constituted from a SiO_2-Y_2O_3 compound such as yttria silicate containing about 1 to 20% by weight of Y_2O_3. On the other hand, when an AlN substrate is used as a cheap substrate for general use, the oxide layer of the AlN substrate is constituted from Al_2O_3.

The metal constituting the metal circuit plates and metal plate is not particularly restricted as far as it forms an eutectic compound with a substrate component and the direct bonding method can be applied. The preferable examples of the metal may include copper, aluminum, iron, nickel, chromium, silver, molybdenum and cobalt, either alone or alloy thereof. However, in view of an electric conductivity and a raw material cost, copper and aluminum

or alloy thereof are preferable.

The thickness of the metal circuit board (circuit layer) is determined in consideration of electric current capacity. When a silicon nitride substrate having a thickness of 0.25 to 1.2 mm and a metal circuit plate having a thickness of 0.1 to 0.5 mm are combined to be bonded each other, influences such as deformation due to the difference in heat expansion coefficients of the two members can be lowered.

When the metal circuit plate or the metal plate is a copper plate, the following bonding operation shall be carried out. Namely, a copper circuit plate is contacted and placed on a predetermined position of the surface of the silicon nitride substrate and the cheap substrate for general use on which the oxide layers are formed. The resulted composite is heated at a temperature lower than melting point of copper (1083 ℃) and not lower than the eutectic temperature of copper-copper oxide (1065 ℃) in condition that the plate is pressed toward the substrate direction. The copper circuit plates and the like are directly bonded to the silicon nitride substrate and the cheap substrate for general use using the generated Cu-O eutectic compound liquid phase as a bonding agent. This direct bonding method is, so-called, a copper direct bonding method (DBC: Direct Bonding Copper method). Further, by mounting a semiconductor chip (Si chip) by way

of solder bonding on a predetermined position of the copper circuit plate directly bonded to the Si_3N_4 substrate, the silicon nitride circuit board of the present invention is produced. When an oxide type ceramic substrate such as Al_2O_3 substrate is used as the cheap substrate for general use, it is needless to say that the oxide layer as described above is not required to be formed.

On the other hand, when the metal circuit plate or the metal plate is an aluminum plate, an Al circuit plate is pressed on the Si_3N_4 substrate and the cheap substrate for general use. The resulted composite is heated at a temperature of eutectic temperature of aluminum- silicon or more in this pressed condition, and the Al circuit plates are directly bonded to the Si_3N_4 substrate using the generated Al-Si eutectic compound as a bonding agent. Further, by mounting a semiconductor chip by way of solder bonding on a predetermined position of the Al circuit plates directly bonded to the Si_3N_4 substrate, the silicon nitride circuit board of the present invention is produced.

Thus, according to the silicon nitride circuit board of the present invention formed by directly bonding metal circuit plates to the surface of a complex substrate using the direct bonding method, and further by mounting a plurality of semiconductor elements on the metal circuit plates bonded to a Si_3N_4 substrate, since no inclusion such as an adhesive and brazing agent exist between the metal

circuit plates an the Si_3N_4 substrate or cheap substrate for general use, heat resistance between both substrates is small, and heat generated from the semiconductor element placed on the metal circuit plates can be quickly dissipated outside of the system.

The method for bonding the metal circuit plates and the like by the active metal method will be described below.

In the active metal method, a metal bonding layer (active metal brazing material layer) having a thickness about 20μm is formed with an Ag-Cu-Ti-based brazing material having a suitable composition ratio which comprises at least one active metal selected from Ti, Zr, Hf and Nb. The metal bonding layer is formed on the surface of a complex substrate, and metal circuit plates such as a copper circuit plates and the like or a metal plate is bonded through this metal bonding layer. The active metal has effects to improve wetting property of a brazing material against the substrate and enhance bonding strength. As a concrete example of the active metal brazing material, a brazing material composition comprising 1 to 10wt.% of the above-described active metal, 15 to 35wt.% of Cu and substantially remaining parts of Ag is suitable. The above-described metal bonding layer is formed by a method in which a composition paste for bonding prepared by dispersing this brazing material composition in an organic

solvent is screen-printed on the surface of the complex substrate and the like.

And, the metal circuit plates or the metal plate that are used as circuit layers are contacted and placed on the metal bonding layer screen-printed, and the resulted composite is heated at a temperature, for example, not less than Ag-Cu eutectic temperature (780℃) and not more than melting point of the metal circuit plates (1083 ℃ in the case of copper), in vacuum or an inert gas atmosphere. In this contact condition, consequently, the metal circuit plates are bonded to the complex substrate through the metal bonding layer.

In the above-described circuit board, the metal circuit plates or the metal plate are integrally bonded to the complex substrate using the direct bonding method or the active metal method, thereby to form a circuit board. However, the circuit board can also be formed by using a metallizing method. Namely, in the metallizing method, a metallizing composition comprising as a main component, for example, a high melting point metal (refractory metal) such as molybdenum (Mo) and tungsten (W) and Ti or compound thereof is baked onto the surface of a complex substrate, to form a high melting point metal-metallized layer as the circuit layer having a thickness of about 15μ m.

When the circuit layer is formed by this metallizing method, it is preferable to form a metal

plating layer having a thickness of 3 to 5μm composed of Ni and Au on the surface of the metallized layer. By forming such a metal plating layer, the surface smoothness of the metallized layer is improved, and adhesion with a semiconductor element is further improved, and further, the solder wetting property can be improved. Therefore, a bonding strength of the semiconductor element bonded by using solder can be enhanced.

The silicon nitride circuit board having the above-described structure is formed by the following procedure. A high thermal conductive silicon nitride substrate particularly having a steeply improved thermal conductivity in addition to a high strength and a high toughness property originally owned by a silicon nitride sintered body is placed on a part to which a structural strength and a heat releasing property are particularly required, while a cheap substrate for general used which can be easily produced such as an alumina substrate and a resin substrate is plated on the other parts, the both substrates are placed on the same plane to form a complex substrate, a metal circuit plate is integrally bonded to the surface of this complex substrate, and further, a semiconductor element is mounted on the metal circuit plates bonded to the high thermal conductive silicon nitride substrate.

Therefore, the production cost is low, and

further, a heat generated from a heat-generating part such as the semiconductor element and the like is quickly transmitted outside of the system through the high thermal conductive silicon nitride substrate. Therefore, the heat releasing property of the module is extremely excellent. Further, when the high thermal conductive silicon nitride substrate having a high strength and a high toughness is placed on a site where the structural strength is particularly required, a maximum deflecting of the circuit board can be secured at a high level. Therefore, cracking due to the fastening of the circuit board in the assembly process does not occur, and a semiconductor apparatus using the circuit board can be mass-produced with a low cost and a high production yield.

Since toughness of the silicon nitride substrate is high, cracking seldom occurs at the connecting portions between the substrate and the metal plate even if the heat cycles are applied, the heat cycle resistance property is remarkably improved, and a semiconductor apparatus excellent in durability and reliability can be provided. Further, since the silicon nitride substrate having a high thermal conductivity is used, degradation in heat resistance property is small and an excellent heat releasing property is demonstrated even if a semiconductor element directing to a high output use or a high-integrated use is mounted.

In particular, since a mechanical strength of the silicon nitride substrate itself is excellent, when required mechanical strength properties are assumed to be constant, the thickness of the substrate can be reduced as compared with the case in which other ceramic substrate is used. Since the thickness of the substrate can be reduced as described above, the heat resistance can be further reduced, and the heat releasing property can be also further improved. Further, since it becomes possible to cope with the required mechanical properties even with a substrate thinner than a conventional substrate, production cost of the substrate can be reduced. Further, when only a conventional high thermal conductive aluminum nitride (AlN) substrate is used as a constituting material of a circuit board, it is necessary to increase the thickness of the aluminum nitride substrate for securing a certain degree of mechanical strength. However, in the circuit board of the present invention, a high heat releasing property is secured and a high strength property is secured simultaneously mainly by the high thermal conductive silicon nitride substrate. In addition, since it is possible to form the cheap substrate for general use which can be easily produced such as an alumina substrate or resin substrate so that the thickness thereof is as small as equivalent to the thickness of the silicon nitride substrate in particular, the heat resistance of the cheap

substrate for general use can be further synergistically reduced. Therefore, according to the present invention, the heat releasing property can be further enhanced as compared with the conventional circuit board using only the conventional cheap substrate for general use having the equivalent thermal conductivity.

BRIEF EXPLANATION OF THE DRAWINGS

Fig. 1 is a cross-sectional view showing a structure of a semiconductor module according to one embodiment of the present invention.

Fig. 2 is a cross-sectional view of a semiconductor module according to another embodiment of the present invention.

Fig. 3 is a cross-sectional view of a semiconductor module according to another embodiment of the present invention.

Fig. 4 is a cross-sectional view showing a structure of a conventional semiconductor module.

Fig. 5 is a cross-sectional view showing a structure of a silicon nitride circuit board according to one embodiment of the present invention.

Fig. 6 is a cross-sectional view of a silicon nitride circuit board according to another embodiment of the present invention.

Fig. 7 is a cross-sectional view showing a

structure of a conventional ceramic circuit board.

Fig. 8 is a plan view showing a constitution example of a silicon nitride circuit board according to the present invention.

Fig. 9 is a cross-sectional view showing one example of a silicon nitride circuit board according to the present invention, and is a cross-sectional view taken in the direction of the arrows along the line IX-IX in Fig. 8.

Fig. 10 is a cross-sectional view showing another example of a silicon nitride circuit board according to the present invention, and is a cross-sectional view taken in the direction of the arrows along the line X-X in Fig. 8.

BEST MODE FOR CARRYING OUT THE INVENTION

The practical embodiments of the present invention are specifically illustrated referring to examples and appended drawings as shown below. First, the high thermal conductive silicon nitride substrate used in the present invention will be described, and then, a semiconductor module and a silicon nitride circuit board using this high thermal conductive silicon nitride substrate as a ceramic substrate will be explained.

Various high thermal conductive silicon nitride substrates which are used as a constitutional material for the semiconductor module and the silicon nitride circuit board of the present invention were produced according to

the following procedure.

Namely, as shown in Tables 1 to 3, rare earth oxides such as Y_2O_3, Ho_2O_3 and the like as a sintering aid and optionally Ti, Hf compound, Al_2O_3 powder, AlN powder are added to silicon nitride raw material powders having an average particle size of 0.55 μm containing oxygen in an amount of 1.3% by weight, the above-described impurity cation elements in a total amount of 0.15% by weight and an α-phase type silicon nitride in an amount of 97%, thereby to prepare various raw material mixtures. The mixtures were subjected to a wet mixing in ethyl alcohol for 72 hours using silicon nitride balls, then dried to prepare raw material powder mixtures respectively. Then, an organic binder in given amount was added to respective raw material powder mixtures, and uniformly mixed. Then, the powder mixtures were press-molded under a molding pressure of 1000 kg/cm^2, to produce a lot of molded bodies having various compositions.

Then, the resulted respective molded bodies were degreased in a gas atmosphere at 700℃ for 2 hours. Thereafter, these degreased bodies were subjected to compacting sintering under sintering conditions shown in Tables 1 to 3. The cooling rates of sintered bodies until the inner temperature of the sintering furnace lowered to 1500℃ were regulated to reach values respectively shown in Tables 1 to 3 by controlling electric current to a

heating apparatus equipped to the sintering furnace, thereby to cool the sintered bodies. Consequently, silicon nitride sintered bodies corresponding to samples 1 to 51 respectively were prepared. Further, the resulted sintered bodies were cut into high thermal conductive silicon nitride substrates having a predetermined rectangular shape of which thickness was 0.3 mm, 0.5 mm or 0.6 mm.

Average values of porosity, thermal conductivity (at 25℃) and three point bending strength at room temperature of thus obtained respective silicon nitride substrates corresponding to samples 1 to 51 were measured. Further, regarding respective silicon nitride substrates, proportion (ratio) of crystal phase occupying grain boundary phase was measured by an X-ray diffraction method, and results shown in Tables 1 to 3 were obtained.

Table 1

SAMPLE	SOURCE COMPOSITION (WEIGHT %)		SINTERING CONDITION TEMPERATURER x TIME	COOLING RATE TO 1500℃ AFTER SINTERING	POROSITY	RATIO OF CRYSTAL PHASE TO GRAIN BOUNDARY PHASE	THERMAL CONDUCTIVITY	THREE-POINT BENDING STRENGTH
	Si_3N_4	Ho_2O_3	(℃) x (hr)	(℃ / hr)	(%)	(%)	(W / m·K)	(M P a)
1	92	8	1950 x 6	100	0.2	22	89	845
2	92	8	1950 x 6	50	0.1	28	92	820
3	92	8	1900 x 6	50	0.6	34	95	800
4	90	10	1950 x 6	100	0.5	25	95	820
5	90	10	1950 x 6	25	0.3	65	99	705
6	90	10	1900 x 6	25	0.9	67	104	805
7	87.5	12.5	1975 x 6	50	0.4	69	114	760
8	87.5	12.5	1900 x 6	25	1.2	70	105	795
9	85	15	1950 x 6	100	1.2	40	102	780
10	85	15	2000 x 6	100	0.6	35	108	700
11	85	15	1950 x 6	25	1.0	65	120	730
12	82.5	17.5	1950 x 6	100	2.3	30	90	755
13	82.5	17.5	2000 x 6	100	1.8	28	96	700
14	82.5	17.5	2000 x 6	25	1.4	32	100	680

Table 2

SAMPLE	SOURCE COMPOSITION (WEIGHT %)						SINTERING CONDITION	COOLING RATE TO 1500℃	POROSITY	RATIO OF CRYSTAL PHASE TO	THERMAL	THREE-POINT
							TEMPERATURER x TIME	AFTER SINTERING		GRAIN BOUDARY PHASE	CONDUCTIVITY	BENDING STRENGTH
	Si_3N_4	Y_2O_3	OTHER COMPONENT		Al_2O_3	AlN	(℃) x (hr)	(℃ / hr)	(%)	(%)	(W / m • K)	(MPa)
15	94.8	5	HfO_2	0.2			1900 x6	50	1.3	50	88	840
16	94	5	HfO_2	1			1900 x6	50	0.2	55	90	960
17	92	5	HfO_2	3			1900 x6	50	0.1	45	75	1060
18	95	2	HfO_2	3			1900 x6	50	0.5	30	65	930
19	92	7.5	HfO_2	0.5			1900 x6	50	0.1	75	95	870
20	94	5	HfO_2	1			1900 x6	100	0.2	45	80	980
21	94	5	HfC	1			1900 x6	100	0.3	55	92	960
22	94	5	HfN	1			1950 x6	100	0.4	55	90	930
23	94	5	$HfSi_2$	1			1950 x6	100	0.4	50	88	910
24	94	5	HfB_2	1			1900 x6	100	0.4	45	83	880
25	94	5	TiO_2	1			1900 x6	100	0.2	48	80	960
26	94	5	ZrO_2	1			1900 x6	100	0.2	45	85	1030
27	94	5	V_2O_5	1			1900 x6	100	0.3	50	90	930
28	94	5	Nb_2O_5	1			1900 x6	100	0.2	48	83	880
29	94	5	Ta_2O_5	1			1900 x6	100	0.4	45	80	900
30	94	5	Cr_2O_3	1			1900 x6	100	0.2	58	100	930
31	94	5	MoO_3	1			1900 x6	100	0.4	40	75	910
32	94	5	WO_3	1			1900 x6	100	0.3	40	75	880
33	94	5	TiC	1			1900 x6	100	0.4	59	95	930
34	94	5	WC	1			1900 x6	100	0.3	49	83	910
35	94	5	TiB_2	1			1900 x6	100	0.4	40	80	950
36	94	5	HfO2 TiO_2	0.5 0.5			1900 x6	100	0.2	46	82	1000

Table 3

SAMPLE	SOURCE COMPOSITION (WEIGHT %)							SINTERING CONDITION TEMPERATURER x TIME (℃) x (hr)	COOLING RATE TO 1500℃ AFTER SINTERING (℃/hr)	POROSITY (%)	RATIO OF CRYSTAL PHASE TO GRAIN BOUDARY PHASE (%)	THERMAL CONDUCTIVITY (W/m·K)	THREE-POINT BENDING STRENGTH (MPa)
	Si_3N_4	RARE EARTH OXIDE		OTHER COMPONENT		Al_2O_3	AlN						
37	88	Ho_2O_3 Y_2O_3	6.5 3.5	HfO_2	2			1900 x 6	50	0.2	55	120	720
38	88	Er_2O_3 Y_2O_3	6.5 3.5	HfO_2	2			1900 x 6	50	0.1	54	119	775
39	88	Yb_2O_3 Y_2O_3	6.5 3.5	HfO_2	2			1900 x 6	50	0.2	60	125	750
40	83.9	Ho_2O_3	15	HfO_2	1	0.1		1900 x 6	50	0.1	49	105	770
41	84	Ho_2O_3	15	HfO_2	0.5	0.5		1900 x 6	50	0.1	30	90	850
42	82	Ho_2O_3	15	HfO_2	2	1		1850 x 6	25	0.1	22	82	900
43	82.5	Ho_2O_3	15	HfO_2	2		0.5	1900 x 6	50	0.1	39	100	880
44	83	Ho_2O_3	15	HfO_2	2		1	1900 x 6	50	0.1	24	88	870
45	82.6	Ho_2O_3	15	HfO_2	2	0.2	0.2	1900 x 6	50	0.1	37	100	885
46	82.5	Er_2O_3	15	HfO_2	2	0.5		1900 x 6	50	0.1	40	94	850
47	82.5	Er_2O_3	15	HfO_2	2		0.5	1900 x 6	50	0.1	38	93	825
48	89.8	Y_2O_3	8	HfO_2	2	0.2		1900 x 6	50	0.1	36	95	800
49	84	Ho_2O_3	15	TiO_2	0.5	0.5		1900 x 6	50	0.1	28	88	820
50	84	Er_2O_3	15	TiO_2	0.5	0.5		1900 x 6	50	0.1	27	88	810
51	84	Yb_2O_3	12.5	TiO_2	0.5	0.5		1900 x 6	50	0.1	27	90	700

As is apparent from the results shown in Tables 1 to 3, in the silicon nitride sintered bodies of the samples 1 to 51, since the raw material composition and impurity amount were suitably controlled, and the cooling rates of the sintered bodies directly after completion of the compacting sintering were lowered as compared with the conventional example, there could be obtained high strength silicon nitride substrates containing a crystal phase in a grain boundary phase and having a high thermal conductivity and a higher heat releasing property as the proportion (ratio) of the crystal phase occupying the grain boundary phase is increased.

On the other hand, 3 to 6% by weight of a Y_2O_3 (yttrium oxide) powder and 1.3 to 1.6% by weight of an alumina powder were added to a silicon nitride raw material powder having an average particle size of 0.60μm containing oxygen in an amount of 1.3 to 1.5% by weight, the above-described impurity cation elements in a total amount of 0.13 to 1.50% by weight and an α-phase type silicon nitride in an amount of 93%, the resulted raw material powder mixture was molded, degreased, then, sintered at 1900℃ for 6 hours, and sintered, then, a furnace cooling which is industrially conducted in general (cooling rate: 400℃/hr) was conducted. The resulted sintered bodies had a thermal conductivity of as low as 25 to 28 w/m·k which is near thermal conductivity of a

silicon nitride sintered body produced according to a conventional general method.

With respect to thus obtained high thermal conductive silicon nitride substrates having a thickness of 0.5 mm corresponding to the resulted samples 1 to 51, a metal circuit plates and a metal plate are integrally bonded to both surfaces of the substrate using the direct bonding method or the active metal method, whereby semiconductor modules were respectively produced.

Fig. 1 is a cross-sectional view showing a structure of a semiconductor module 1a according to one embodiment of the present invention.

In Fig. 1, copper plates 3 as the metal circuit plates are integrally bonded to the front surface of the high thermal conductive silicon nitride substrate 10, and a copper plate 4a as the backing metal plate is bonded to the rear surface of the high thermal conductive silicon nitride substrate 10. Thus the semiconductor module 1a is constituted.

The copper plates 3, 4a in the semiconductor module 1a are bonded to the high thermal conductive silicon nitride substrate 10 by using the direct bonding method, so-called DBC method. For the copper plates 3, 4a when such a DBC method is used, it is preferable to use copper such as tough pitch copper containing oxygen in a proportion of 100 to 3000 ppm. However, it is also possible to use

oxygen-free copper of which surface is oxidized. Instead of a simple plate of copper and copper alloy, there can be also used a clad plate formed by copper material with other metal member, and at least a surface portion of the clad plate to be contacted to the high thermal conductive silicon nitride substrate 10 is constituted by the copper material.

The copper plate 3 bonded to the front surface of the high thermal conductive silicon nitride substrate 10 is a member which becomes a mounting site for mounting a semiconductor part and the like, and patterned into a predetermined circuit form. A semiconductor element 7 is solder-bonded to a predetermined site of the copper plates 3, an electrode portion of the semiconductor element 7 and an electrode portion of the copper plates 3 are electrically connected by a bonding wire 8. The copper plate (backing copper plate) 4a bonded to the rear surface of the high thermal conductive silicon nitride substrate 10 is a member for preventing a bending and the like of the high thermal conductive silicon nitride substrate 10 at the bonding operation. The copper plate is bonded and formed to approximately whole rear surface of the high thermal conductive silicon nitride substrate 10 in condition that is separated around the center into two parts. As shown in Fig. 1, a thickness t1 of the copper plate 4a bonded to the rear surface may be the same as that of the copper plate 3

i.e., metal circuit plates which become the mounting site of a semiconductor part and the like. However, it is preferable to use a copper plate having a thickness not more than the thickness t0 of the copper plates 3, further preferably a thickness corresponding to 70 to 90% of the thickness t0 of the copper plates 3.

On the other hand, as shown in Fig. 3, when a function as a heat sink plate for improving the heat releasing property is imparted to the metal plate 4b to be bonded to the rear surface of the high thermal conductive silicon nitride substrate 10, it is preferable that the thickness t2 of the metal plate 4b to be bonded to an apparatus casing 9 or a mounting board is 2-fold or more of the thickness t0 of the metal circuit plates.

By the structure that the thickness t2 of the metal plate 4b bonded to the rear surface of the high thermal conductive silicon nitride substrate 10 is 2-fold or more of the thickness t0 of the metal circuit plates 3, the effect that this metal plate 4b functions as a heat sink can be increased even if a heat sink plate is not used. Therefore, the heat releasing property of the module can be further improved.

In this embodiment, the semiconductor module 1a shown in Fig. 1 is obtained by bonding the copper plates 3, 4a to the high thermal conductive silicon nitride substrate 10 by the DBC method. However, it may be a semiconductor

module obtained by bonding the copper plates 3, 4a to the high thermal conductive silicon nitride substrate 10 by the active metal method. The above-described active metal method is a method in which the copper plates 3, 4a are bonded to the high thermal conductive silicon nitride substrate 10 through a brazing material (hereinafter, referred to as active metal-containing brazing material) layer containing at least one active metal selected from, for example, Ti, Zr, Hf, Nb and the like. As a composition of the active metal-containing brazing material to be used, a composition obtained by adding 1 to 10% by weight of at least one active metal selected from Ti, Zr, Hf, Nb and the like to an Ag-Cu-based brazing material or Cu-based brazing material as a main component having, for example, an Ag-Cu eutectic composition (72% by weight of Ag - 28% by weight of Cu) or the near composition, and the like are exemplified. Further, it is also possible to add 1 to 10% by weight of In to the active metal-containing brazing material.

As like the semiconductor module 1a shown in Fig. 1, the module obtained by bonding the copper plates 3, 4a to the high thermal conductive silicon nitride substrate 10 by the DBC method has merits that the structure is simple, a high bonding strength is obtained, the production process can be simplified, and the like. On the other hand, in the module obtained by bonding the copper plates 3, 4a

to the high thermal conductive silicon nitride substrate 10 by the active metal method, a high bonding strength is obtained, and further, the active metal-containing brazing material layer also functions as a stress modulating layer. Therefore, the reliability of the module can be improved. Because of these reasons, it is preferable to select the bonding method in accordance with the required properties or uses and the like.

Further, when the metal circuit plates and the metal plate are bonded to the high thermal conductive silicon nitride substrate 10 by the active metal method, it is also possible to use various metal plates according to use, for example, a nickel plate, a tungsten plate, a molybdenum plate, an alloy plate thereof, a clad plate (including a clad plate with the copper plate) and the like, without limiting to the copper plate.

The semiconductor module 1a as described above can be produced, for example, by the following procedure. Namely, for example, an oxygen-containing copper plate such as tough pitch copper is processed into a predetermined form (regarding the copper plate 3, it has a circuit pattern form). The resulted copper plates 3, 4a are respectively contacted and placed on the surface of the high thermal conductive silicon nitride substrate 10, and by heating at a temperature of not higher than a melting point (1356 K) of copper and not lower than an eutectic

temperature of copper with copper oxide (1338 K), whereby the respective copper plates 3, 4a are bonded. Further, a semiconductor element 7 is solder-bonded to a predetermined position of the copper plate 3, and an electrode of the semiconductor element 7 and an electrode of the copper plate 3 are connected by a bonding wire 8 to produce a semiconductor module. It is preferable that the atmosphere in bonding operation with heating of this copper plate is an inert gas atmosphere when an oxygen-containing copper plate is used as the copper plate.

Further, the semiconductor module obtained by bonding the metal circuit plates and metal plate by the active metal method can be produced, for example, by the following procedure. First, as like the above-described semiconductor module 1a, the copper plates 3, 4a each having a predetermined shape are prepared. On the other hand, a paste prepared from the active metal-containing brazing material as described above is applied, for example, to the surface of the high thermal conductive silicon nitride substrate 10. Regarding the application thickness of the brazing material layer, it is preferable that the thickness of the brazing material layer after the bonding with heating is not so large, in view of improvement of cooling and heating cycle property. Then, the copper plates 3, 4a are respectively laminated and placed on the surface of the high thermal conductive

silicon nitride substrate 10, and by conducting heat treatment at a temperature corresponding to a brazing material used, whereby the metal circuit plate 3 and the metal plate 4a are bonded. Further, the semiconductor element 7 is solder-bonded to a predetermined position on the copper plate 3, and an electrode of semiconductor element 7 and an electrode of the copper plate 3 are connected by a bonding wire 8 thereby to produce a semiconductor module.

The semiconductor module 1a shown in Fig. 1 is fastened and fixed to the apparatus casing 9 by inserting an attaching screw 6a into a penetration bore for attaching a screw 11 formed on a periphery part of the silicon nitride substrate 10. However, since a silicon nitride sintered body has a high hardness, and therefore, a perforating process is not easy. Therefore, to simplify the production process, for example, as shown in Fig. 2, a case 12 in a form of a frame to which a penetration bore for attaching screw 11a is formed is prepared, and an inner peripheral edge portion of this case 12 is pressed onto an outer periphery edge portion of the semiconductor module, whereby the module can be also fixed by being pressed to a device casing 9 by means of an attaching screw 6b.

In the semiconductor module having the above-described structure, since the high thermal conductive silicon nitride substrate 10 having a sharply

improved thermal conductivity in addition to a high strength and a high toughness property originally owned by the silicon nitride sintered body is used as a ceramic substrate, cracking seldom occurs on the substrate 10 by impacts caused in heat cycles and assembling process. In particular, the module does not need any heat sink plate for enhancing the heat releasing property and the structural strength. Therefore, the structure of the semiconductor module is simplified and the production cost is steeply reduced. Further, the module can be miniaturized and a high density mounting becomes possible. Consequently, a down-sizing of the semiconductor apparatus can be effectively accomplished.

Specific examples and evaluation results are described below.

Example 1

As a high thermal conductive silicon nitride substrate, high thermal conductive silicon nitride substrates 10 having a thickness of 0.5 mm which carries on the surface an oxide layer (SiO_2 layer) having a thickness of 4μm were prepared by adopting silicon nitride substrates corresponding to the samples 1 to 51 shown in Tables 1-3 and by oxidizing them. Further, copper plates 4a as a metal plate having a thickness of 0.25 mm and metal plates 3 as metal circuit plates each having a thickness of 0.3 mm in a predetermined form made of tough pitch copper

(oxygen content: 300 ppm) were prepared by pressing process.

Then, as shown in Fig. 1, two copper plates 3, 4a were directly contacted and placed on both surfaces of the high thermal conductive silicon nitride substrate 10 to form a composite. The composite was heated for bonding at 1348 K in nitrogen gas atmosphere, and further, the semiconductor element 7 was solder-bonded to the copper plate 3, and wire bonding was performed thereby to obtain an intended semiconductor module 1a.

On the other hand, as a comparative example, a semiconductor module of the comparative example was produced in the same manner as in Example 1 except that an aluminum nitride substrate having a thickness of 0.6 mm was used instead of the above-described high thermal conductive silicon nitride substrate 10.

Thus obtained semiconductor module 1a of Example 1 and semiconductor module of comparative example were subjected to a heat cycle test (TCT: 233 K× 30 minutes + RT × 10 minutes + 398 K× 30 minutes is set to one cycle), and ratios of cracking formation occurred on the ceramic substrates were measured. As a result, in the semiconductor module of Example 1, no cracking occurred even after 100 cycles of TCT. On the other hand, in the semiconductor module of comparative example, the cracking occurred on 5 to 9% of the ceramic substrates after 100 cycles of TCT.

Example 2

As a high thermal conductive silicon nitride substrate, highly thermal conductive silicon nitride substrates 10 having a thickness of 0.5 mm corresponding to the samples 1 to 51 were prepared. Further, copper plates 3, 4 having a thickness of 0.3 mm and copper plates 5 having a thickness of 0.25 mm respectively having a predetermined form were prepared by a pressing process.

A paste prepared from an active metal-containing brazing material having a composition of In:Ag:Cu:Ti = 14.0:59.0:23.0:4.0 was applied on both surfaces of the high thermal conductive silicon nitride substrate 10. Then, the copper plates 3, 4a were laminated and placed through this applied layer to form a composite. Then, the composite was heated for integration in a nitrogen gas atmosphere. Further, the semiconductor element 7 was solder-bonded to the copper plate 3, and wire bonding was effected to obtain an intended semiconductor module.

Thus obtained semiconductor module was subjected to the heat cycle test (TCT) under the same condition as in Example 1. As a result, excellent results as in Example 1 were obtained, and an excellent reliability of the module against the cooling and heating cycles was confirmed.

Example 3

As a high thermal conductive silicon nitride substrate, high thermal conductive silicon nitride substrates 10 having a thickness of 0.5 mm which carries on

the surface an oxide layer (SiO_2 layer) having a thickness of 4μm were prepared by adopting silicon nitride substrates corresponding to the above-described samples 1 to 51 and by oxidizing them. Further, copper plates 3 having a thickness of 0.3 mm and metal plates 4 having a thickness of 0.6 mm in a predetermined form made of tough pitch copper (oxygen content: 300 ppm) were prepared by pressing process.

Then, as shown in Fig. 3, two copper plates 3, 4a were directly contacted and placed on both surfaces of the high thermal conductive silicon nitride substrate 10 to form a composite. The composite was then heated for bonding at 1348 K in a nitrogen gas atmosphere. Further, the semiconductor element 7 was solder-bonded to the copper plate 3, and wire bonding was performed to obtain an intended semiconductor module.

On the other hand, as a comparative example, a semiconductor module of the comparative example was produced in the same manner as in Example 3 except that aluminum nitride substrates 2a, 2b each having a thickness of 0.6 mm were used instead of the above-described high thermal conductive silicon nitride substrate 10.

Thus obtained semiconductor module of Example 3 and the semiconductor module of comparative example were subjected to heat cycle test (TCT: 233 K× 30 minutes + RT× 10 minutes + 398 K× 30 minutes is set to one cycle), and

ratios of the cracking formation occurred on the ceramic substrates were measured. As a result, in the semiconductor module 1b of Example 3, no cracking occurred even after 100 cycles of TCT. On the other hand, in the semiconductor module of comparative example, the cracking occurred on 4 to 7% of the ceramic substrates after 100 cycles of TCT.

Example 4

As a high thermal conductive silicon nitride substrate, high thermal conductive silicon nitride substrates 10 having a thickness of 0.5 mm corresponding to the samples 1 to 51 were prepared. Further, copper plates 3 having a thickness of 0.3 mm and copper plates 4b having a thickness of 0.6 mm respectively having predetermined forms were prepared by pressing process.

A paste prepared from an active metal-containing brazing material having a composition of In:Ag:Cu:Ti = 14.0:59.0:23.0:4.0 was applied to both surfaces of the high thermal conductive silicon nitride substrate 10. The copper plates 3, 4b were laminated and placed through this applied layer to form a composite. Then, the composite was heated for integration in a nitrogen gas atmosphere, and further, the semiconductor element 7 was solder-bonded to the copper plate 3, and wire bonding was effected to obtain an intended semiconductor module.

Thus obtained semiconductor module was subjected to the heat cycle test under the same condition as in

Example 3. As a result, excellent results as in Example 3 were obtained, and an excellent reliability of the module against cooling and heating cycles was confirmed.

Further, according to the semiconductor module of the present invention, since the high thermal conductive silicon nitride substrate 10 having a sharply improved thermal conductivity in addition to a high strength and a high toughness property originally owned by a silicon nitride sintered body is used. Therefore, the module does not need both a rear copper plate (backing metal plate) and a heat sink plate for enhancing the heat releasing property and the structural strength, and the structure of the module is simplified and the production cost is steeply reduced. Further, heat generated from a heat generating part such as the semiconductor element 7 and the like mounted on the substrate is transmitted outside of the system quickly through the high thermal conductive silicon nitride substrate 10. Therefore, the heat releasing property of the module is extremely excellent.

Further, since the high thermal conductive silicon nitride substrate 10 having a high strength and a high toughness is used, a maximum deflecting of the module can be secured at a high level. Therefore, cracking due to fastening does not occur even when the module is fixed to an apparatus casing 9 by an attaching screw 6a in the assembly process. As a result, a semiconductor apparatus

using the semiconductor module can be mass-produced with a low cost and a high production yield.

Since toughness of the high thermal conductive silicon nitride substrate 10 is high, cracking does not occur on the connecting portion between the substrate 10 and the metal circuit plates or the metal plates 4a, 4b even if the heat cycles are applied. As a result, the heat cycle resistance property is remarkably improved, and a semiconductor apparatus excellent in durability and reliability can be provided.

Further, since the silicon nitride substrate 10 having a high thermal conductivity is used, degradation in heat resistance property is small and an excellent heat releasing property is demonstrated even if the semiconductor element 7 directing to a high output use or a high integrated use is mounted.

In particular, since mechanical strength of the silicon nitride substrate itself is excellent, when required mechanical strength properties are assumed to be constant, the thickness of the substrate can be reduced as compared with the case in which other ceramic substrate is used. Namely, in a conventional semiconductor module, the thickness of a ceramic substrate is generally from 0.6 to 1.0 mm, however, by using the high thermal conductive silicon nitride substrate used in the present invention, the thickness can be reduced as thin as to 0.1 mm to 0.6

mm. Since the thickness of the substrate can be reduced as described above, the heat resistance can be further reduced, and the heat releasing property can be further improved. Further, since it is possible to cope with the required mechanical properties even with a substrate thinner than a conventional substrate, production cost of the substrate can be reduced.

Then, by bonding metal plates for integration on both surfaces of two high thermal conductive silicon nitride substrates having a thickness of 0.3 mm and 0.6 mm respectively prepared as the above-described samples 1 to 51 by using the direct bonding method or the active metal method for forming multi-layered structure, silicon nitride circuit boards were produced respectively.

Fig. 5 is a cross-sectional view showing a structure of a silicon nitride circuit board according to one embodiment of the present invention.

In the Fig. 5, two high thermal conductive silicon nitride substrates 210a, 210b are integrally bonded through a copper plate 204 as the metal plate, and copper plates 203 as the metal plates are bonded to the front surface of the high thermal conductive silicon nitride substrate 210b. On the other hand, a copper plate 205 is also bonded to the rear surface of the high thermal conductive silicon nitride substrate 210a in the same manner, thus the silicon nitride circuit board 209A is

constituted.

The copper plates 203, 204, 205 in the silicon nitride circuit board 209A are bonded to the high thermal conductive silicon nitride substrates 210a, 210b by the direct bonding method, so-called DBC method. When such a DBC method is used for the copper plates 203, 204, 205, it is preferable to use copper such as tough pitch copper containing oxygen in a proportion of 100 to 3000 ppm, and it is also possible to use oxygen free copper of which surface is oxidized. Instead of a simple plate of copper and copper alloy, there can be also used a clad plate formed by cladding copper material with other metal member, at least surface portion of the clad plate to be contacted with the high thermal conductive silicon nitride substrates 210a, 210b is constituted by the copper material.

The copper plates 203 bonded to the front surface of the highly thermal conductive silicon nitride substrate 210b are members which become a mounting portion of a semiconductor part and the like, and patterned into a predetermined circuit form. A semiconductor element 207 is solder-bonded to a predetermined site of the copper plate 203. An electrode portion of the semiconductor element 207 and an electrode portion of the copper plate 203 are electrically connected by a bonding wire 208. The copper plate 205 bonded to the rear surface of the high thermal conductive silicon nitride substrate 210a is a member for

preventing a bending and the like of the high thermal conductive silicon nitride substrate 210a in bonding operation. The copper plate 205 is bonded and formed on approximately whole rear surface of the high thermal conductive silicon nitride substrate 210a in condition that is separated around the center into two parts. The thickness of the copper plate 205 on the rear surface may be the same as that of the copper plate 203 which becomes the mounting portion of a semiconductor part and the like. However, it is preferable to use a copper plate having a thickness corresponding to 70 to 90% of the thickness of the copper plate 203.

Though the silicon nitride circuit board 209A shown in Fig. 5 is obtained by bonding the copper plates 203, 204, 205 onto two high thermal conductive silicon nitride substrates 210a, 210b by the DBC method, however, a silicon nitride circuit board 209B obtained by bonding the copper plates 203, 204, 205 onto two high thermal conductive silicon nitride substrates 210a, 210b by the active metal method may also be permissible as shown in Fig. 6. The above-described active metal method is a method in which the copper plates 203, 204, 205 are bonded to two high thermal conductive silicon nitride substrates 210a, 210b through a brazing material (hereinafter, referred to as active metal-containing brazing material) layer containing at least one active metal selected from, for

example, Ti, Zr, Hf, Nb and the like.

Each of the silicon nitride circuit boards 209A, 209B as described above is formed in a multi-layered structure in which two high thermal conductive silicon nitride substrates 210a, 210b to which metal plates 203, 204, 205 such as copper circuit plates and the like are bonded by the direct bonding method or active metal method are multi-layered through the metal plates 203, 204, 205. Therefore, it becomes possible to perform a three-dimensional assembly for the module, so that the circuit board can be miniaturized while securing an enlarged area for the mounting portion and the circuit constituting portions, and a small-sizing and a high-density mounting can be accomplished.

Further, by providing the plural-layered structure of the high thermal conductive silicon nitride substrates 210a, 210b having metal plates 203, 204, 205 such as a copper plate, a package and the like can be produced. In addition, since a metal plate such as a copper plate is used as the circuit constituting portions, current loss can be improved as compared with a conventional plural-layered package, and the structure of the present invention can be applied to a high frequency type semiconductor element and a heavy current type semiconductor element.

Then, specific examples and evaluation results are described below.

Example 5

As a high thermal conductive silicon nitride substrate, high thermal conductive silicon nitride substrates 210a, 210b having a thickness of 0.3 mm and 0.6 mm respectively which carry on the surface an oxide layer (SiO_2 layer) having a thickness of 4μm were prepared by adopting silicon nitride substrates corresponding to the samples 1 to 51 and by oxidizing them. Further, copper plates 203, 204 having a thickness of 0.3 mm and metal plates 205 having a thickness of 0.25 mm in a predetermined form made of tough pitch copper (oxygen content: 300 ppm) were prepared and formed by the pressing process.

Then, as shown in Fig. 5, three copper plates 203, 204, 205 were directly contacted and placed on both surfaces of the high thermal conductive silicon nitride substrates 210a, 210b to form a composite. The composite was heated for bonding at 1348 K in a nitrogen gas atmosphere, thereby to obtain an intended silicon nitride circuit board 209A.

On the other hand, as a comparative example, an aluminum nitride circuit board of the comparative example was produced in the same manner as in Example 5 except that aluminum nitride substrates 202a and 202b having a thickness of 0.8 mm and 0.6 mm respectively were used instead of the above-described high thermal conductive silicon nitride substrates 210a, 210b.

Thus obtained silicon nitride circuit board of Example 5 and the aluminum nitride circuit board of comparative example were subjected to the heat cycle test (TCT: 233 K × 30 minutes + RT × 10 minutes + 398 K× 30 minutes is set to one cycle), and ratios of the cracking formation occurred on the ceramic substrates were measured. As a result, in the silicon nitride circuit board of Example 5, no cracking occurred even after 100 cycles of TCT. On the other hand, in the aluminum nitride circuit board of comparative example, the cracking occurred on 5 to 9% of the ceramic substrates after 100 cycles of TCT.

Example 6

As a high thermal conductive silicon nitride substrate, high thermal conductive silicon nitride substrates 210a, 210b having a thickness of 0.3 mm and 0.6 mm respectively corresponding to the samples 1 to 51 were prepared. Further, copper plates 203, 204 having a thickness of 0.3 mm and copper plates 205 having a thickness of 0.25 mm respectively having predetermined forms were prepared and formed by the pressing process in the same manner as in Example 5.

A paste prepared from an active metal-containing brazing material having a composition of In:Ag:Cu:Ti = 14.0:59.0:23.0:4.0 was applied on both surfaces of the high thermal conductive silicon nitride substrates 210a, 210b. The copper plates 203, 204, 205 were laminated and

placed through this applied layer to form a composite. Then, the composite was heated for integration in a nitrogen gas atmosphere, thereby to obtain an intended plural-layered silicon nitride circuit board 209B.

Thus obtained plural-layered silicon nitride circuit board 209B was subjected to the heat cycle test under the same condition as in Example 5. As a result, excellent results as in Example 5 were obtained, and an excellent reliability of the circuit board against the cooling and heating cycles was confirmed.

In the silicon nitride circuit boards 209A, 209B of the respective examples, the high thermal conductive silicon nitride substrates 210a, 210b particularly having a sharply improved thermal conductivity in addition to a high strength and a high toughness property originally owned by a silicon nitride sintered body are used. Therefore, the heat generated from a heat-generating part such as the semiconductor element 207 and the like mounted on the substrate is transmitted outside of the system quickly through the high thermal conductive silicon nitride substrates 210a, 210b, so that the heat releasing property of the circuit board is extremely excellent.

Further, since the high thermal conductive silicon nitride substrates 210a, 210b having a high strength and a high toughness are used, a maximum deflecting of the circuit board can be secured at a high

level. Therefore, the cracking caused by fastening the circuit board in the assembling process does not occur, and a semiconductor device using the circuit board can be mass-produced with a low cost and a high production yield.

Since toughness of the high thermal conductive silicon nitride substrates 210a, 210b is high, the cracking seldom occurs on the connecting portion between the substrates 210a, 210b and the metal circuit plates or metal plates 203, 204, 205 even if the heat cycles are applied. Further, the heat cycle resistance property of the circuit board is remarkably improved, and a semiconductor device excellent in durability and reliability can be provided.

Further, since the silicon nitride substrates 210a, 210b having a high thermal conductivity are used, degradation in heat resistance property is small and an excellent heat releasing property is demonstrated even if the semiconductor element 207 directing to a high output use or a high integrated use is mounted.

Then, examples of a silicon nitride circuit board in which a high thermal conductive silicon nitride substrate and an Alumina substrate as a cheap substrate for general use are placed on the same plane are described below.

Examples 7 to 9

5% by weight of a Y_2O_3 (yttrium oxide) powder having an average particle size of 0.7μm and 1.0% by

weight of a Al_2O_3 (alumina) powder having an average particle size of 0.5μm as a sintering aid were added to a silicon nitride raw material powder having an average particle size of 0.55 μm containing oxygen in an amount of 1.3% by weight, impurity cation elements, Li, Na, K, Fe, Ca, Sr, Ba, Mn, and B in a total amount of 0.15% by weight and an α-phase type silicon nitride in an amount of 97%. The resulted mixtures were subjected to wet mixing in ethyl alcohol for 24 hours using, then dried to prepare raw material powder mixtures. Then, an organic binder in a predetermined amount was added to the resulted raw material powder mixtures, and uniformly mixed. Then, the raw material mixtures were press-molded under a molding pressure of 1000 kg/cm^2, thereby to produce a lot of molded bodies each having a size of length 80 mm × width 50 mm× thickness 1 to 5 mm. Then, the resulted molded bodies were degreased in a gas atmosphere at 700℃ for 2 hours. Then, these degreased bodies were subjected to compacting sintering by maintaining the degreased bodies in a nitrogen gas atmosphere under pressure of 7.5 atom at 1900℃ for 6 hours. Then, cooling rates of the sintered bodies until the inner temperature of the sintering furnace lowered to 1500 ℃ were regulated to reach 100℃/hr respectively by controlling electric current to a heating apparatus equipped to the sintering furnace thereby to gradually cool the sintered bodies. Further, the resulted

respective sintered bodies were subjected to an abrasion process to prepare silicon nitride (Si_3N_4) substrates for Examples 7 to 9, each having a thermal conductivity k of 70 w/m· k and a thickness of 0.4 mm, 0.6mm and 0.8 mm, respectively.

On the other hand, as the cheap substrate for general use having a thermal conductivity of less than 60 w/m· k, alumina (Al_2O_3) substrates for Examples 7 to 9, having a thermal conductivity k of 20 w/m· k and the same thickness were prepared as for the above-described Si_3N_4 substrate.

As shown in Figs. 8 and 9, a Si_3N_4 substrate 302 and a Al_2O_3 substrate 302a each having the same thickness were combined on the same plane to form complex substrates 310 respectively. Namely, the Si_3N_4 substrate 302 is placed on a part to which a semiconductor element 306 is mounted, while the Al_2O_3 substrate 302a is placed on the other parts, thereby to form a complex substrate 310.

As shown in Figs. 8 and 9, a brazing material having a composition of Ag 30wt.% - Cu 65wt.% - Ti 5wt.% was screen-printed on positions of the front surfaces of the silicon nitride substrate 302 and the alumina substrate 302a to which a circuit layer is formed and positions on the rear surfaces of the substrates to which a metal plate (copper plate) is bonded. The printed brazing material are dried to form active metal brazing material layers 307a,

307b having a thickness of 20 μm. Copper circuit plates 304 each having a thickness of 0.3 mm and a copper plate (backing copper plate or rear copper plate) 305 having a thickness of 0.25 mm each composed of tough pitch electrolytic copper are contacted and placed on predetermined positions of the active metal brazing material layers 307a, 307b to form composites. Then, the composites were maintained at 850 ℃ in vacuum for 10 minutes in the contacting condition to make bonded articles. Then, the respective bonded articles were subjected to etching treatment, to form predetermined patterns (circuit layers). Further, the semiconductor element 306 was bonded through a solder layer 308 to a center portion of the copper circuit plate 304 bonded to the upper surface of the Si_3N_4 substrate 302, thereby to make a lot of silicon nitride circuit boards 301 of Examples 7 to 9.

Comparative Example 1

A ceramic circuit board of Comparative Example 1 was produced by integrally bonding the copper circuit plates and the metal plate to the surface of the substrate by the active metal method likewise in Examples 7 to 9, except that a ceramic substrate composed only of an aluminum nitride (AlN) sintered body having a thickness of 0.8 mm and a thermal conductivity k of 182 w/m· k was used instead of the complex substrate 310 composed of the Si_3N_4

substrate 302 and the Al_2O_3 substrate 302a used in Examples 7 to 9.

Maximum deflection and bending resistance strength of thus prepared circuit boards of Examples 7 to 9 and Comparative Example 1 were measured. As a result, it was found that the silicon nitride circuit boards 301 of Examples 7 to 9 had 2-fold or more of the maximum deflection and the bending resistance strength as compared with those of the circuit board of Comparative Example 1 in which only a conventional aluminum nitride substrate was used. Further, it was also confirmed that the deflection and the bending resistance strength are improved with reduction of the thickness of the silicon nitride circuit boards. Further, it was confirmed that heat releasing property of whole circuit board can be further improved by reduction of the thickness of the substrate since the heat resistance can be lowered.

The respective silicon nitride circuit boards of the examples were bonded on a heat sink 309 as shown in Fig. 9, then, mounted on a board in assembly process. As a result, a semiconductor device using the circuit board could be produced with a high production yield without causing cracking due to the fastening operation for fixing the circuit board.

Further, the respective circuit boards were subjected to a heat cycle resistance test in which a

temperature increasing and decreasing cycle wherein the test sample was heated from -45 ℃ to a room temperature (RT), subsequently heated from the room temperature to +125℃ , then, again cooled to -45 ℃ via room temperature was repeated and cycle number until cracking occurred on substrate portion was measured.

As a result, it was found that there was no cracking of the Si_3N_4 substrate and the Al_2O_3 substrate and no releasing or peeling of the metal circuit board (Cu circuit board) or the metal plate, and an excellent heat cycle resistance property was manifested even after 1000 cycles elapsed, in the silicon nitride circuit boards of Examples 7 to 9. On the other hand, it was confirmed that the circuit board of Comparative Example 1 caused cracking after 100 cycles and had a low durability.

Example 10

The Si_3N_4 substrates having a thickness of 0.4 mm, 0.6 mm and 0.8 mm respectively and a thermal conductivity k of 70 w/m· k, which were prepared in Examples 7 to 9, were heated in an oxidizing furnace at a temperature of 1300 ℃ for 12 hours for oxidation of whole surface of the substrate and oxide layers having a thickness of 2μ m were formed. The oxide layer was formed of a SiO_2 film.

On the other hand, the Al_2O_3 substrates having a thickness of 0.4 mm, 0.6 mm and 0.8 mm respectively and a thermal conductivity k of 20 w/m· k, which were prepared in

Examples 7 to 9, were obtained.

As shown in Fig. 10, the Si_3N_4 substrate 302 and the Al_2O_3 substrate 302a having the same thickness were combined on the same plane to form complex substrates 310 respectively. Namely, the Si_3N_4 substrate 302 was placed on a position to which the semiconductor element was mounted, while, the Al_2O_3 substrate 302a was placed on the other position, thereby to form the complex substrate 310.

Then, on the front side of the complex substrate 310 in which each Al_2O_3 substrate 302a was combined with the Si_3N_4 substrate 302 on which the oxide layer 303 was formed, copper circuit plates each composed of a tough pitch electrolytic copper having a thickness of 0.3 mm were contacted and placed, while, on the rear side, a metal plate composed of a tough pitch copper having a thickness of 0.25 mm was contacted and placed as a backing material, to form a laminate. Then, by inserting this laminate in a heating oven at 1075℃ in which a nitrogen gas atmosphere was controlled and by heating for 1 minute, the metal circuit plates or the metal plate were directly bonded to both surfaces of respective complex substrates 310. Further, the semiconductor element was solder-bonded to the copper circuit plate, thereby to prepare the silicon nitride circuit boards 301a of Example 10, respectively.

Each silicon nitride circuit boards 301a has a structure in which the oxide layer 303 composed of SiO_2 is

formed on whole surface of the Si_3N_4 substrate 302, the copper circuit plates 304 as the metal circuit plates are directly bonded to the front surface of the complex substrate 310 comprising the Si_3N_4 substrate 302 and the Al_2O_3 substrate 302a, while, the metal plate 305 as the rear copper plate is directly bonded, and further, the semiconductor element 306 is integrally bonded through the soldering layer 308 formed on a predetermined position of the copper circuit plates bonded to the front side of the Si_3N_4 substrate 302, as shown in Fig. 10. When the copper circuit plates 304 or the metal plate 305 are bonded to both surfaces of the complex substrate 310, the metal plate 305 as the backing copper plate is effective since it contributes to heat releasing acceleration and bending prevention.

The maximum deflection of the silicon nitride circuit board of Example 10 in which the circuit layers were formed by the direct bonding method as described above was from 0.8 to 1.6 mm, the bending resistance strength was from 550 to 900 MPa, and there were obtained physical properties equivalent to those in Examples 7 to 9 wherein the circuit boards were formed by the active metal method. Further, even after 1000 cycles elapsed in the heat cycle resistance test, there was no cracking of the Si_3N_4 substrate and the Al_2O_3 substrate and no releasing of the metal circuit plates and the metal plate, and an excellent

heat cycle resistance property was manifested.

Industrial Applicability

As described above, according to the semiconductor module of the present invention, since a high thermal conductive silicon nitride substrate having a sharply improved thermal conductivity in addition to a high strength and a high toughness property originally owned by a silicon nitride sintered body is used, cracking seldom occurs on the substrate by impacts to be applied in heat cycles and construction, and the semiconductor module does not need both a rear copper plate (backing metal plate) and a heat sink plate for enhancing a heat releasing property and a structural strength. Therefore, the structure of the semiconductor module is simplified and the production cost is steeply reduced, and further, the semiconductor module can be miniaturized and a high-density mounting becomes possible.

Further, in the silicon nitride circuit board of the present invention, a plurality of high thermal conductive silicon nitride substrates to which metal plates such as copper circuit plates and the like are bonded are plural-layered through the metal plate. Therefore, it becomes possible to perform a three-dimensional assembly, so that the circuit board can be miniaturized with enlarging area of a mounting portion and circuit

constituting portions, and a small-sizing and a high-density mounting can be accomplished.

Further, heat generated from a heat-generating part such as a semiconductor element and the like mounted on the substrate is transmitted outside of the system quickly via the high thermal conductive silicon nitride substrate. Therefore, the heat releasing property of the module is extremely excellent. Further, since the silicon nitride substrate having a high strength and a high toughness is used, a maximum deflecting of the module or circuit board can be secured at a high level. Therefore, cracking due to fastening of the module in the assembly process does not occur, and a semiconductor device using the semiconductor module can be mass-produced with a low cost and a high production yield.

According to the silicon nitride circuit board of the present invention, since a high thermal conductive silicon nitride substrate particularly having a steeply improved thermal conductivity in addition to a high strength and a high toughness property originally owned by a silicon nitride sintered body is placed on a part to which a structural strength and a heat releasing property are particularly required, while a cheap substrate for general used which can be easily produced such as an alumina substrate and a resin substrate is placed on the other parts, and both the substrates are placed on the

same plane to form a complex substrate, the production cost of the circuit board is low. Further, by placing the silicon nitride substrate which has a high strength and a high toughness property on a position to which a structure strength is required, a maximum deflection of the circuit board can be secured at a high level. Therefore, cracking due to fastening of the circuit board in the assembly process does not occur, and a semiconductor device using the circuit board can be mass-produced with a low cost and a high production yield.

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CLAIMS

1. A semiconductor module comprising:

a high thermal conductive silicon nitride substrate having a thermal conductivity of 60 w/m· k or more,

a semiconductor element mounted on said high thermal conductive silicon nitride substrate,

metal circuit plates bonded to said high thermal conductive silicon nitride substrate at a side to which the semiconductor element is mounted, and

single metal plate bonded to said high thermal conductive silicon nitride substrate at a side to which the semiconductor element is not mounted but an apparatus casing or a mounting board is bonded.

2. The semiconductor module according to Claim 1, wherein said metal plate to be bonded to the apparatus casing or the mounting board has a thickness less than that of said metal circuit plate.

3. The semiconductor module according to Claim 1, wherein said metal plate to be bonded to the apparatus casing or the mounting board has a thickness more than two times of that of said metal circuit plate.

4. The semiconductor module according to Claim 1,

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wherein said high thermal conductive silicon nitride substrate is made of a silicon nitride crystal phase and a grain boundary phase, and a ratio of the crystal compound phase in the grain boundary phase is 20% or more based on the whole grain boundary phase.

5. The semiconductor module according to Claim 1, wherein said high thermal conductive silicon nitride substrate is made of a silicon nitride crystal phase and a grain boundary phase, and a ratio of the crystal compound phase in the grain boundary phase is 50% or more based on the whole grain boundary phase.

6. The semiconductor module according to Claim 1, wherein said high thermal conductive silicon nitride substrate contains impurity cation elements of Li, Na, K, Fe, Ca, Sr, Ba, Mn and B in a total amount of 1.0% by weight or less.

7. The semiconductor module according to Claim 1, wherein said metal circuit plates and said metal plate are bonded to said high thermal conductive silicon nitride substrate by a direct bonding method.

8. The semiconductor module according to Claim 1, wherein said metal circuit plates and said metal plate are

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bonded to said high thermal conductive silicon nitride substrate by an active metal brazing method.

9. A silicon nitride circuit board comprising:

a plurality of high thermal conductive silicon nitride substrates each having a thermal conductivity of 60 w/m· k or more and

a metal plate which is bonded to said high thermal conductive silicon nitride substrate, and has a portion at which a plurality of said high thermal conductive silicon nitride substrates are laminated through said metal plate to form plural-layered structure.

10. A silicon nitride circuit board, wherein a high thermal conductive silicon nitride substrate having a thermal conductivity of 60 w/m· k or more and a substrate having a thermal conductivity of less than 60 w/m· k are placed on the same plane, and

metal circuit plates are bonded to at least said high thermal conductive silicon nitride substrate having a thermal conductivity of 60 w/m· k or more.

11. The silicon nitride circuit board according to Claim 9 or 10, wherein said high thermal conductive silicon nitride substrate is made of a silicon nitride crystal phase and a grain boundary phase, and a ratio of the

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crystalline compound phase in the grain boundary phase is 20% or more based on the whole grain boundary phase.

12. The silicon nitride circuit board according to Claim 9 or 10, wherein said high thermal conductive silicon nitride substrate is made of a silicon nitride crystal phase and a grain boundary phase, and a ratio of the crystalline compound phase in the grain boundary phase is 50% or more based on the whole grain boundary phase.

13. The silicon nitride circuit board according to Claim 9 or 10, wherein said high thermal conductive silicon nitride substrate contains impurity cation elements of Li, Na, K, Fe, Ca, Sr, Ba, Mn and B in a total amount of 1.0% by weight or less.

14. The silicon nitride circuit board according to Claim 9 or 10, wherein said metal circuit plates and the metal plate are bonded to said high thermal conductive silicon nitride substrate by a direct bonding method.

15. The silicon nitride circuit board according to Claim 9 or 10, wherein said metal circuit plates and the metal plate are bonded to said high thermal conductive silicon nitride substrate by an active metal brazing method.

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ABSTRACT OF THE DISCLOSURE

There is provided a semiconductor module which comprises a high thermal conductive silicon nitride substrate 10 having a thermal conductivity of 60 w/m· k or more, a semiconductor element 7 mounted on this high thermal conductive silicon nitride substrate 10, metal circuit plates 3 which are bonded on the semiconductor element-mounted side of this high thermal conductive silicon nitride substrate 10 and single metal plate 4a which is bonded to a side opposing to the semiconductor element- mounted side of this high thermal conductive silicon nitride substrate and is bonded on an apparatus casing 9 or a mounting board. By this constitution, there can be provided a semiconductor module having a simple structure, which can be miniaturized, and having an improved structure strength and an excellent heat cycle resistance property without requiring a heat sink plate or the like.

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CLAIMS

1. A semiconductor module comprising:

a high thermal conductive silicon nitride substrate having a thermal conductivity of 60 w/m. k or more,

a semiconductor element mounted on said high thermal conductive silicon nitride substrate,

metal circuit plates bonded to said high thermal conductive silicon nitride substrate at a side to which the semiconductor element is mounted, and

single metal plate bonded to said high thermal conductive silicon nitride substrate at a side to which the semiconductor element is not mounted but an apparatus casing or a mounting board is bonded; and wherein said high thermal conductive silicon nitride substrate is made of a silicon nitride crystal phase and a grain boundary phase, and a ratio of the crystal compound phase in the grain boundary phase is 50% or more based on the whole grain boundary phase.

2. The semiconductor module according to Claim 1, wherein said metal plate to be bonded to the apparatus casing or the mounting board has a thickness less than that of said metal circuit plate.

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3. The semiconductor module according to Claim 1, wherein said metal plate to be bonded to the apparatus casing or the mounting board has a thickness more than two times of that of said metal circuit plate.

4. The semiconductor module according to Claim 1, wherein said high thermal conductive silicon nitride substrate contains impurity cation elements of Li, Na, K, Fe, Ca, Sr, Ba, Mn and B in a total amount of 1.0% by weight or less.

5. The semiconductor module according to Claim 1, wherein said metal circuit plates and said metal plate are bonded to said high thermal conductive silicon nitride substrate by an active metal brazing method.

6. The semiconductor module according to Claim 1, wherein said metal circuit plates and said metal plate are bonded to said high thermal conductive silicon nitride substrate by an active metal brazing method.

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7. A silicon nitride circuit board comprising:

a plurality of high thermal conductive silicon nitride substrates each having a thermal conductivity of 60 w/m. k or more and

a metal plate which is bonded to said high thermal conductive silicon nitride substrate, and has a portion at which a plurality of said high thermal conductive silicon nitride substrates are laminated through said metal plate to form plural-layered structure; and wherein said high thermal conductive silicon nitride substrate is made of a silicon nitride crystal phase and a grain boundary phase, and a ratio of the crystalline compound phase in the grain boundary phase is 50% or more based on the whole grain boundary phase.

8. A silicon nitride circuit board, wherein a high thermal conductive silicon nitride substrate having a thermal conductivity of 60 w/m. k or more and a substrate having a thermal conductivity of less than 60 w/m. k are placed on the same plane, and

metal circuit plates are bonded to at least said high thermal conductive silicon nitride substrate having a thermal conductivity of 60 w/m. k or more; and wherein said high thermal conductive silicon nitride substrate is made of a silicon nitride crystal phase and a grain boundary phase, and a ratio of the crystalline compound phase in

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the grain boundary phase is 50% or more based on the whole grain boundary phase.

9. The silicon nitride circuit board according to Claim 7 or 8, wherein said high thermal conductive silicon nitride substrate contains impurity cation elements of Li, Na, K, Fe, Ca, Sr, Ba, Mn and B in a total amount of 1.0% by weight or less.

10. The silicon nitride circuit board according to Claim 7 or 8, wherein said metal circuit plates and the metal plate are bonded to said high thermal conductive silicon nitride substrate by a direct bonding method.

11. The silicon nitride circuit board according to Claim 7 or 8, wherein said metal circuit plates and the metal plate are bonded to said high thermal conductive silicon nitride substrate by an active metal brazing method.

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