CURING LIQUID RESIN ENCAPSULANTS OF MICROELECTRONICS COMPONENTS WITH MICROWAVE ENERGY

Field of the Invention

The present invention relates generally to micro-electronics components, and more particularly to packaging for micro-electronics components.

Background of the Invention

The continuing trend in the microelectronics industry is to develop faster, smaller, and cheaper devices. This trend, known as "downsizing", has required manufacturers to develop new methods of connecting integrated circuit (IC) chips to printed circuit boards (PCBs) and other devices. An IC chip is a thin wafer of silicon processed to produce active solid state devices that are connected to form logic units, memory storage cells, and the like.

Traditionally, IC chips were packaged in plastic housings that provided an electrical interconnection between the IC chip and the PCB on which it was mounted, provided mechanical strength, and protected the IC chip from moisture and other environmental hazards. However, to facilitate downsizing, IC chips have become "package-less" and, increasingly, are directly mounted to a PCB or other device. Exemplary package-less mounting techniques include "flip chip" and "chip on board" (COB). Flip

chip and COB mounting of IC chips are used in a variety of consumer products including watches, computers, telecommunications devices, and automotive electronics. Flip chip and COB provide higher packaging density and increase the speed of the IC chip because of shorter electrical paths and increased numbers of interconnects.

Flip chip mounting involves directly attaching an IC chip to a PCB with the active face of the IC chip down. The connection points from the internal circuitry of an IC chip are at the "active" surface of the silicon wafer in the form of small conductive (typically aluminum) pads. A structure, referred to as a bump, is placed over each connection point. These bumps typically are formed from solder and are used to conductively secure the IC chip to a PCB. In some cases, conductive adhesives are used to secure the IC chip to the PCB, in lieu of solder. COB mounting involves mounting an IC chip directly onto a substrate with the active side of the IC chip up. Wires extending from the active side are connected to the PCB where necessary.

IC chips directly attached to PCBs via COB and flip chip are typically mechanically fragile and require protection from moisture and other environmental hazards. This protection and increased strength is obtained through the use of liquid resin encapsulation techniques. Without proper protection, most IC chips are exposed, during use, to thermal stresses that result from the different coefficients of thermal expansion of the silicon chip and the PCB material. For flip chip mounting, these thermal stresses can cause failure of the solder joints connecting the IC chip to the PCB. These thermal stresses can also cause failure when conductive adhesives are used, because conductive adhesives often do not create as strong of a connection as solder. For

COB mounting, these thermal stresses can cause IC chip warpage and cracking, and can damage the wires interconnecting the IC chip and PCB.

To overcome these difficulties, a polymeric encapsulation material, referred to as "underfill" is typically added between the PCB and IC chip (and subsequently cured) for flip chip mountings, and a polymeric encapsulation material, referred to as "glob top" is dispensed on top of the IC chip, electrical connections, and portions of the PCB (and subsequently cured) for COB mountings. When cured, underfill locks the high expansion of the PCB (which is typically formed from some organic-based material) in step with the low expansion of the silicon chip. As a result, the solder joints are no longer exposed to thermal stresses. Underfill also makes conductive adhesives a viable alternative to solder connections because the underfill material increase the strength of the connection of the IC chip to the PCB. Both underfill and glob top provide protection from environmental hazards such as moisture ingress and oxidation. Both glob top and underfill are preferred assembly techniques for a variety of electronics products because they allow manufacturers to make relatively thin devices that are stronger and lower in cost than traditional plastic packages.

Resins used as glob top and underfill encapsulants can cure to a hardened state at room temperature, but the time to cure can be rather long. Curing these resins by adding heat can reduce, often dramatically, the time required to cure. In typical COB and flip chip manufacturing processes, heat is applied by placing the PCB and IC chip in an oven for specific periods of time depending on the temperature within the oven. For example, it may take up to several hours to properly cure an encapsulant between 130°C and 170°C. Unfortunately, the addition of heat

from conventional ovens at faster rates may lead to void generation within the resin due to fast reaction rates. Fast heating rates may also damage other components. Furthermore, the exotherm release from the reaction can damage an IC chip being encapsulated and the underlying PCB to which the IC chip is attached. Also, the addition of heat from conventional ovens can cause stresses to build up in an IC chip being encapsulated and in the underlying PCB to which the IC chip is attached, which become "locked-in" upon curing of the encapsulating resin. These stresses result because of the different coefficients of thermal expansion for the IC chip and PCB. These locked in stresses can reduce the performance and life of the IC chip.

Heating techniques utilizing single frequency microwave energy are known. However, problems such as arcing and local heating often arise due to the rather unpredictable nature of conductive materials when exposed to microwave energy. Furthermore, the time required to cure resin via single microwave energy can be too long for many electronic components to withstand without incurring some damage from non-preferential localized heating or arcing.

Room temperature techniques, such as those utilizing UV light, are described in *Low Stress Aerobic Urethanes Lower Costs For Microelectronic Encapsulation* (Ed Wienckowski, Dymax Corporation, Torrington, CT). Unfortunately, the resin must be directly and completely exposed to the UV light to achieve efficient curing. Because of the various shapes and configurations of many electrical components, shadow problems can prevent the UV light from reaching some portions of the resin, thereby increasing the time required to cure the resin.

Summary of the Invention

It is therefore an object of the present invention to decrease the time required to cure encapsulating resins used in COB and flip chip mounting of IC chips to PCBs.

It is another object of the present invention to facilitate the use of microwave energy to selectively cure encapsulating resins used in COB and flip chip mounting techniques without causing damage to an IC chip or PCB via arcing or non-preferential local heating.

It is another object of the present invention to reduce the build up and lock-in of stresses during the curing of resins encapsulating microelectronics components assembled using COB and flip chip.

These and other objects are accomplished, according to the present invention, by systems and methods of surface mounting microelectronic components to rapidly produce microelectronic assemblies having reduced residual stresses therein. The present invention is particularly applicable to COB surface mounting wherein an IC chip is secured, with its active side up, to a PCB and then encapsulated with resin. The present invention is also particularly applicable to flip chip surface mounting wherein an IC chip is secured, with its active side down, to a PCB and encapsulating resin is applied between the IC chip active side and the PCB. In both cases, the encapsulating resin is irradiated with variable frequency controlled microwave energy to rapidly cure the resin and to lock the IC chip and PCB into a low stress structure that is capable of withstanding repeated thermal shock and thermocycling. Furthermore, the cured encapsulating resin protects the IC chip from various environmental hazards. The use of variable frequency microwave radiation decreases the time to cure compared with conventional heating techniques.

According to one aspect of the present invention directed to COB mounting techniques, a microelectronic component is conductively secured to a substrate surface, and a portion of the component and the substrate surface adjacent the component is encapsulated with a curable resin. The curable resin may be either a thermosetting or thermoplastic resin. The curable resin may have a coefficient of thermal expansion less than or equal to the coefficient of thermal expansion of the microelectronic component and greater than or equal to the coefficient of thermal expansion of the substrate. Preferably, the curable resin has a coefficient of thermal expansion less than the coefficient of thermal expansion of the microelectronic component and greater than the coefficient of thermal expansion of the substrate. The curable resin is swept with one or more ranges of microwave frequencies to selectively cure the resin and produce a microelectronic assembly having reduced residual stresses therein. Each range of microwave frequencies is selected to heat the substrate to a temperature less than the temperature to which the curable resin is heated. Also, each range is selected such that the microwave frequencies within each range do not cause damage to the microelectronic component or substrate via local heating or arcing. Typically, the resin is heated to between about 110°C and about 165°C. The temperature of the resin is typically between about twenty percent and fifty percent (20%-50%) greater than the heated temperature of the substrate. The resulting COB assembly has reduced residual stresses compared with COB assemblies produced using conventional heating techniques for resin curing.

According to another aspect of the present invention directed to flip chip mounting techniques, an integrated circuit chip is conductively secured to a substrate surface such that the active surface of the

chip is in opposing spaced apart relation with the substrate surface. A curable resin is provided between the integrated circuit chip active surface and the substrate surface so as to contact both the chip active surface and the substrate surface. The curable resin is swept with one or more ranges of microwave frequencies to selectively cure the resin and produce a microelectronic assembly having reduced residual stresses therein. The resulting flip chip assembly has reduced residual stresses compared with flip chip assemblies produced using conventional heating techniques for resin curing.

The present invention is advantageous for surface mounting techniques such as flip chip and COB because the time required to cure the encapsulating resin is decreased. Decreasing time to cure facilitates increasing overall production rates which may lead to lower production costs. Furthermore, the build up and lock-in of stresses caused by conventional heating techniques is reduced because the encapsulant can be selectively cured quickly and without causing the temperature of the PCB to rise as much as the IC chip and encapsulant.

Brief Description of the Drawings

Fig. 1 illustrates a typical prior art package for an IC chip.

Fig. 2 is a side view of an IC chip mounted to a PCB via COB and having a glob top encapsulant thereon.

Fig. 3 is a side view of an IC chip mounted to a PCB via flip chip and having underfill between the active side of the IC chip and the PCB.

Fig. 4 schematically illustrates a method of surface mounting a microelectronic component to produce a microelectronic assembly having reduced residual stresses therein, according to the present invention.

Figs. 5A, 5B, 5C illustrate the dispensing of underfill between the active side of an IC chip mounted to a PCB and the PCB.

Fig. 6 illustrates the application of variable frequency microwave energy to cure a glob top encapsulant. The glob top encapsulant is illustrated in an exploded view for clarity.

Fig. 7 illustrates the application of variable frequency microwave energy to cure an underfill between the active side of an IC chip and PCB.

Figs. 8A, 8B illustrate cure data for various samples processed with variable frequency microwave energy in accordance with the present invention.

Fig. 9 illustrates curing encapsulating resins with conventional heat furnaces whereupon the microelectronic component and supporting structure are exposed to thermal stresses.

Figs. 10A, 10B, 10C illustrate the build up and lock in of stresses during curing using conventional heat furnaces.

Fig. 11 illustrates the use of variable frequency controlled microwave energy to cure an encapsulant and to alleviate stresses in a flip chip during curing.

Fig. 12 illustrates the temperature differential between an encapsulating resin and a PCB during the application of variable frequency controlled microwave energy to cure the resin.

Detailed Description of Preferred Embodiments

The present invention now is described more fully hereinafter with reference to the accompanying drawings, in which preferred embodiments of the invention are shown. This invention may, however, be embodied in many different forms and should not be construed as limited to the embodiments set forth

herein; rather, these embodiments are provided so that this disclosure will be thorough and complete, and will fully convey the scope of the invention to those skilled in the art.

Referring to **Fig. 1**, a typical prior art package for an IC chip is illustrated. As shown, IC chips typically were secured within plastic housings having a plurality of legs configured to be inserted through holes in a PCB and soldered thereto. The current trend in the microelectronics industry, as illustrated in **Figs. 2** and **3**, is to eliminate these housings and directly bond microelectronic components, such as IC chips, to the PCB. The present invention involves placing a microelectronics component, such an IC chip, on a PCB, applying an encapsulating resin, and then curing the resin by irradiating it with variable frequency microwave radiation.

Referring now to **Fig. 4**, a method, according to the present invention, of surface mounting a microelectronic component to produce a microelectronic assembly having reduced residual stresses therein is illustrated. Steps include: conductively securing a microelectronic component to a substrate surface (Block **100**); encapsulating a portion of the microelectronic component and a portion of the substrate surface adjacent the microelectronic component with a curable resin (Block **102**); and sweeping the curable resin with at least one range of microwave frequencies to selectively cure the encapsulating resin (Block **104**).

Referring back to **Fig. 2**, a COB mounting technique is illustrated. A silicon IC chip **10** is mounted on a PCB **12** and is encapsulated with a polymeric resin **14** (referred to as a "glob top"). A typical IC chip **10** comprises an uncased integrated silicon substrate **16** and external connectors or wires **18** extending from the active side **10a** of the IC chip. The wires **18** are attached to the PCB **12** at appropriate

connection points, as illustrated. A PCB **12** typically comprises a flexible or rigid electrically insulating material, such as, but not limited to, a fiberglass-reinforced resin or ceramics, upon which a pattern of electrical conductors (not shown) are formed to interconnect individual components which will be mounted upon the PCB. As is known to those with skill in the art, the electrical conductors are formed on the PCB via any suitable process such as photo-imaging, chemical etching, and the like.

In the illustrated embodiment of **Fig. 2**, the chip **10** is bonded to the PCB **12** using a suitable conductive adhesive **20**, such as an adhesive filled with silver. Adhesives, solder and the like, and the devices used to apply them, may serve as means for conductively securing a microelectronics component to a substrate surface. The IC chip **10** is electrically interconnected to the electrical conductors on the PCB **12** via conductive wires **18** formed of conductive material, such as gold, aluminum, silver, copper, and the like. The wires **18** are bonded to the electrical conductors using any suitable bonding technique, such as tape automated bonding, or ultrasonic bonding. The IC chip **10** and the interconnection with the PCB **12** are mechanically fragile and environmentally sensitive because of no packaging surrounding the IC chip. The "packaging" is provided by polymer-based encapsulants which are used to add mechanical strength, improve handling, provide environmental protection, and provide electrical isolation.

Still referring to **Fig. 2**, once the IC chip **10** and wires **18** are properly bonded to the PCB **12** and electrical conductors, respectively, a glob-top encapsulant **14** of resin is dispensed over the bare IC chip **10** including the wires **18** extending therefrom, and over a portion of the PCB **12** to form a bubble-like encapsulant structure. Automated dispensers are well

known by those having skill in the art. An exemplary automated dispenser is an Asymtek system which is programmed to dispense an appropriate adhesive encapsulant in the desired location, either as a glob top encapsulant or an underfill encapsulant. An adhesive dispenser serves as means for encapsulating a portion of a microelectronic component and a portion of a substrate surface adjacent the microelectronic component with a curable resin. The encapsulant **14** is dispensed while in a viscous state and flows to cover the desired areas. The encapsulant **14** can comprise any curable material which exhibits qualities suitable for encapsulating electronic components, such as being electrically insulating, moisture resistant, and adhesive to the PCB. Preferably, encapsulants have a coefficient of thermal expansion less than the coefficient of thermal expansion of the microelectronic components and greater than the coefficient of thermal expansion of the PCBs. As is known to those having skill in the art, other techniques and devices may serve as means for applying encapsulating resin to the IC chip and PCB, such as screen printing. In addition, the shape of the glob top can be changed by utilizing dams surrounding the IC chip, as is known by those skilled in the art.

Referring now to **Fig. 3**, the flip chip mounting technique is illustrated. An IC chip **30** is mounted to a PCB **32** with the active side **30a** of the IC chip facing downwards toward the PCB. Solder bumps **34** extending from the various connection points on the active side **30a** of the IC chip **30**, are shown securing the IC chip to the PCB **32**. Encapsulating resin **36** (referred to as "underfill") is provided between the active side **30a** of the IC chip and the PCB **32**, preferably by capillary action. However, the resin **36** may be provided between the active side **30a** of the IC chip **30** and the PCB **32** using other techniques known to

those with skill in the art. As is known to those having skill in the art, additional resin material can be applied around the periphery of the IC chip **30** to form fillets before the application of a glob top.

The underfill **36** protects the active side **30a** of the IC chip **30** as well as the interconnection of the IC chip and PCB **32**. The underfill **36** is especially useful in preventing moisture ingress into the interconnection of the IC chip **30** and PCB **32**. This feature is important when IC chips are adhesively mounted to a PCB. Silver-based epoxy adhesives are common and can form dendrites in the presence of moisture. Furthermore, the underfill **36** produces a very strong bond of the IC chip **30** to the PCB **32** when cured so that the typically lower mechanical strength of adhesives, as compared with solder, is overcome.

Referring now to **Figs. 5A, 5B**, and **5C**, the providing or dispensing of underfill **36** between the active side **30a** of an IC chip **30** and a PCB **32** is illustrated. In the illustrated embodiment, underfill **36** is needle-dispensed in liquid form along one or two sides of the IC chip **30**, which is soldered to the PCB (**Fig. 5A**). Capillary action pulls the underfill **36** under the entire IC chip **30** (**Fig. 5B**). Fillets **38** may be added as shown in **Fig. 5C**, and the underfill **36** is ready for curing. A syringe-like needle may serve as means for applying resin. Other techniques and devices may serve as means for applying encapsulating resin to the IC chip **30** and PCB **32** such as screen printing. Screen printing techniques are described in *Advances in Packaging & Assembly Po. mers* (Dr. Ken Gilleo, Alpha Metals, Cranston, RI), w ch is incorporated herein by reference in its entirety.

A particularly suitable class of encapsulating resins, for both COB and flip chip mounting techniques, are thermosetting resins. By the term, "thermosetting", it is meant that the resin

irreversibly solidifies or "sets" when completely cured by activating the curing agents, such as by heating using microwave irradiation. A particularly suitable class of thermosetting resins are epoxies. In addition, thermoplastic resins may serve as suitable encapsulating resins for both glob top and underfill. Suitable resins include unsaturated polyesters, phenolics, acrylics, silicones, polyurethanes, polyamides and the like, and mixtures and blends thereof. Resins can include various additives commonly employed with thermosetting and thermoplastic resins such as fillers, curing agents, colorants, pigments, thickening agents, and the like.

For flip chip mounting, the encapsulating resin preferably has good adhesion to both the IC chip and the PCB. Preferably, encapsulating resins for both flip chip and COB have high glass transition temperatures, good adhesive properties to various materials, good chemical resistance, low moisture absorption, good mechanical strength, high modulus, and high ionic purity. As is known to those having skill in the art, modulus is a measure of stiffness and is related to the chain length or the cross-link density, chemical composition and molecular structure. A high modulus polymer is stiff and resists deflection. Ionic purity is important because polymers with high ionic content can accelerate corrosion of circuitry and chip metallization. Preferable material characteristics of an encapsulating resin for underfill are described in *Advances in Flip-Chip Underfill Flow and Cure Rates and their Enhancement of Manufacturing Processes and Component Reliability* (Daqing M. Shi and James W. Carbin, Thermoset Plastics, Inc., Indianapolis, IN), which is incorporated herein by reference in its entirety. Preferably, encapsulating resins for underfill have a coefficient of thermal expansion less than the coefficient of thermal expansion of the IC

chip and greater than the coefficient of thermal expansion of the PCB.

According to the present invention, after an encapsulant is dispensed over an IC chip (COB) or is applied as underfill (flip chip), it is cured rapidly to a solid form by irradiating it with microwave energy. Preferably, variable frequency microwave energy **40** is applied to cure the encapsulant as shown in **Fig. 6** for COB and **Fig. 7** for flip chip. In **Fig. 6**, the glob top encapsulant **14** is shown in exploded view for clarity; however, it shall be understood that the glob top encapsulant, prior to curing with microwave energy **40**, is dispensed on top of the microelectronics component **10** and the underlying PCB or substrate **12**.

Variable frequency microwaves can rapidly and uniformly cure the encapsulating resin for a variety of surface mounting techniques including COB and flip chip, without adversely affecting the IC chip, electrical conductors, wires, or PCB encapsulated therewithin. Single frequency microwave energy and RF energy may be used in combination with variable frequency microwave energy in certain applications, as long as the selected single frequency does not cause damage to the various components.

The use of variable frequency microwave energy may be combined with other curing techniques such as applying hot air to the encapsulating resin. The present invention is advantageous over slower prior art curing methods wherein the IC chip and PCB assembly are typically moved to an oven and heated to high temperatures (typically between 130°C and 170°C) from about thirty (30) minutes up to about several hours in some cases.

Referring now to **Fig. 8A**, the time to cure various samples with variable frequency controlled microwave energy, in accordance with the present invention, as compared with conventional methods is

tabulated. Various PCBs having various circuit configurations thereon with IC chips mounted via flip chip and COB were placed within a variable frequency microwave oven. The dimensions of the PCBs were generally about six inches by four inches (6" x 4"). Degree of cure was measured using Differential Scanning Calorimetry (DSC) techniques, which are known to those having skill in the art. DSC also enables the measurement of the glass transition temperature by measuring the change in the heat flow rate accompanying any changes in the material. After heating with variable frequency controlled microwave energy, the samples were frozen until the degree of cure was measured. As shown in **Fig. 8A**, the samples processed with variable frequency controlled microwave energy, in accordance with the present invention, reached cure in significantly less time than comparable samples processed with conventional heat, and at a lower temperature. **Fig. 8B** illustrates the results obtained for a variable frequency controlled microwave processed sample at 165°C for two minutes. The temperature of the IC chip on each PCB was monitored throughout the cure cycle. As illustrated by the thermal profile, a high heating rate on the IC chip occurs leading to generally defect-free curing of the underfill encapsulant.

Conventional curing using heat causes stresses to build up within an IC chip, as a result of the different coefficients of thermal expansion of the IC chip and PCB. These stresses become locked-in upon curing of the encapsulant. Typically, a PCB has a higher coefficient of thermal expansion than that of an IC chip or other microelectronics component mounted thereto. As shown in **Fig. 9**, the IC chip **30**, PCB **32** and encapsulant **36** are all heated to the same temperature within conventional heat furnaces. The IC chip temperature (T_c) and PCB temperature (T_b) are the

same as the temperature within the furnace (T_f) during heating and cooling ($T_c = T_b = T_f$). Conventional heat furnaces do not have the capability to selectively heat components or materials.

Referring now to **Figs. 10A, 10B, 10C**, the build up and lock-in of stresses using conventional heat furnaces is illustrated. The IC chip **50** has a low coefficient of thermal expansion and the PCB **52** has a high coefficient of thermal expansion. During heating and cooling, the IC chip **50** and PCB **52** expand and contract by different amounts causing stresses (**Figs. 10A, 10B**). As shown in **Fig. 10C**, a result of this differential expansion and contraction is that the IC chip **50** may warp or bend. When the encapsulating resin (not shown), either glob top or underfill, cures, this warpage and the associated stresses are locked-in within the IC chip **50** and substrate **52**.

The use of variable frequency microwave energy to cure an encapsulating resin helps alleviate stresses during curing. This is because the frequency or range(s) of frequencies can be selected so that the encapsulant and IC chip are selectively heated without heating the PCB to the same temperature. This is shown in **Fig. 11**, wherein the PCB **52** has a lower temperature (T_b) during curing than either the temperature (T_c) of the IC chip **50** or the temperature (T_u) of the encapsulant. Because the temperature (T_b) of the PCB **52** is not as high as the temperature (T_u) of the encapsulant and the temperature (T_c) of the IC chip **50**, the expansion and contraction of the PCB **52** is not as great as when the entire IC chip and PCB assembly is heated. When variable frequency microwave energy is applied, according to the present invention, the encapsulant temperature (T_u) is generally equivalent to the IC chip temperature (T_c). Both the encapsulant temperature (T_u) and the IC chip temperature (T_c) are greater than the PCB temperature (T_b) and the

temperature (T_f) within the furnace ($T_u = T_c > T_b > T_f$). As a result, stresses imparted upon the IC chip **50** and interface with the PCB **52** are minimal. Upon curing of the encapsulant **54**, minimal stresses are locked into the interface of the flip chip and IC chip **50**.

The stresses generated within an IC chip during curing can be correlated to the radius of curvature of the IC chip after cooling has taken place. Optical interferometry can be used to measure the radius of curvature exhibited by an IC chip. The radius of curvature measured on IC chips processed with variable frequency controlled microwave energy, in accordance with the present invention, has been observed to be on average 918 millimeters (mm) with a standard deviation of 25.13. This is an improvement of 50% over similar samples processed using conventional heating.

In addition, the cure rate of encapsulating resin has significant effects on the properties of the end product. Warpage of an IC chip can result from exposure to the high temperatures required to cure the resin. Furthermore, it is necessary to keep cure temperatures below the reflow temperature of solder. The use of variable frequency controlled microwave irradiation allows the appropriate frequency or range(s) of frequencies to be selected to rapidly cure the encapsulating resin without causing the IC chip to warp and without reaching the reflow temperature of solder.

When heated via variable frequency microwave energy, the temperature of a PCB containing IC chips is high in the area of the IC chips and the encapsulating resin, and low in areas not containing IC chips. Typically, when using variable frequency microwave energy to cure underfill encapsulating resins for flip chip mounting, the temperature of the encapsulating resin and IC chip may be elevated to 160°C and higher.

The remainder of the PCB typically remains at a lower temperature in the range of about 100°C to 140°C. **Fig. 12** illustrates this. The top curve **75** represents the temperature of an encapsulating resin during variable frequency microwave processing. The bottom curve **77** represent the temperature of the PCB upon which an IC chip is encapsulated via the resin. Time in seconds is plotted along the X axis **80** and temperature in degrees Centigrade is plotted along the Y axis **82**.

The variation of the temperature of a PCB may depend on various factors including the thickness of the PCB, thermal conductivity of the PCB material, and the printed circuit geometry on the PCB. The variation of the temperature of the PCB when compared to that of the IC chip/encapsulating resin area during a cure process carried out at about 160°C is in the range of about forty percent to eighty percent (40% - 80%) of the encapsulating resin cure temperature.

A variable frequency microwave furnace may serve as means for sweeping resins with at least one range of microwave frequencies to cure the resin. A particularly preferred variable frequency microwave furnace is described in U.S. Patent No. 5,321,222, to Bible et al., the disclosure of which is incorporated herein by reference in its entirety. A variable frequency microwave furnace typically includes a microwave signal generator or microwave voltage-controlled oscillator for generating a low-power microwave signal for input to the microwave furnace. A first amplifier may be provided to amplify the magnitude of the signal output from the microwave signal generator or the microwave voltage-controlled oscillator. A second amplifier is provided for processing the signal output by the first amplifier. A power supply is provided for operation of the second amplifier. A directional coupler is provided for detecting the direction of a signal and further

directing the signal depending on the detected direction. Preferably a high-power broadband amplifier, such as, but not limited to, a traveling wave tube (TWT), tunable magnetron, tunable klystron, tunable twystron, and a tunable gyrotron, is used to sweep a range of frequencies of up to an octave in bandwidth spanning the 300 MHz to 300 GHz frequency range.

Appropriate use of variable frequency microwave curing, as disclosed herein, enhances uniform curing from one group of microelectronic components to the next because placement within the microwave furnace is not critical. By contrast, with single frequency microwave curing, each group of encapsulated components typically must be oriented precisely the same way to achieve identical curing time and quality. Another advantage of using variable frequency microwave curing, as disclosed herein, is a reduction of the effects of thermal stresses. By selecting frequencies that cure a particular encapsulant without causing excessive heating of the encapsulated component and underlying substrate, damage from thermal stresses may be reduced or avoided. The present invention facilitates short curing times and selective heating of an encapsulant without substantial heating of the PCB. Using the present invention, materials adjacent to a surface mounted microelectronics component having coefficients of thermal expansion different from that of the microelectronics component, do not have enough heat or time to excessively expand or contract. As such, thermal stresses do not become locked-in upon curing of the encapsulating resin.

The practical range of frequencies within the electromagnetic spectrum from which microwave frequencies may be chosen is about 0.90 GHz to 40 GHz. Every group of encapsulated components irradiated with microwave energy typically has at least one range or

window of frequencies, within this overall range that will cure the encapsulant without causing damage to other components. The term "window", as used herein, refers to a range of microwave frequencies bounded on one end by a specific frequency and bounded on the opposite end by a different specific frequency. Above or below a particular window of damage-free frequencies, damage may occur to the encapsulated component, substrate, or adjacent components. A window may vary depending on component configuration, geometry, and material composition. A window may also vary depending on the nature and configuration of sub-components within a component other than an IC chip being encapsulated. Sub-components may have different windows of damage-free frequencies, as well. An encapsulated IC chip or component may have a sub-component therein requiring a narrow window of frequencies, and a sub-component therein requiring a wide window of frequencies. The selection of a damage-free window for a particular IC chip or component is typically obtained either empirically through trial and error, or theoretically using power reflection curves and the like.

Within a window of damage-free frequencies for a particular encapsulated microelectronics component, it is generally desirable to select the frequencies that result in the shortest time to cure. Preferably, a group is processed with a subset of frequencies from the upper end of each window. Typically, more modes can be excited with higher frequencies than with lower frequencies which means better uniformity in curing is typically achieved. Additionally, more microwave energy absorption and less microwave penetration depth, results in shorter cure times. However, any subset of frequencies within a window of damage-free frequencies may be used.

Many components that are irradiated with microwave energy have multiple windows of frequencies within which an encapsulant will cure without causing damage to the component or underlying substrate. For example, an encapsulated IC chip or microelectronics component (either COB or flip chip) may be irradiated with microwave energy without damage between 3.50 GHz and 6.0 GHz, and may also be irradiated without damage between 7.0 GHz and 10.0 GHz. The availability of additional windows provides additional flexibility for achieving rapid, yet damage-free curing. Often times, complex geometrical configurations and material combinations are encountered which may actually shrink or close a particular window of frequencies available for processing. The availability of alternative windows permits encapsulants to be irradiated with microwave energy without having to resort to other curing methods.

Preferably, the step of curing is performed by "sweeping" the encapsulant with variable frequencies from within a particular window of damage-free frequencies. The term "sweeping", as used herein, refers to irradiating the encapsulant with many of the frequencies within a particular window. Frequency sweeping results in uniformity of heating because many more complementary cavity modes can be excited. Sweeping may be accomplished by launching the different frequencies within a window either simultaneously, or sequentially. For example, assume the window of damage-free frequencies for a particular encapsulated component is 2.60 GHz to 7.0 GHz. Frequency sweeping would involve continuously and/or selectively launching frequencies within this range in any desirable increments, (e.g., sweeping between 2.6 and 3.3 GHz) such as 2.6001 GHz, 2.6002 GHz, 2.6003 GHz ... 3.30 GHz, etc. Virtually any incremental launching pattern may be used.

The rate at which the different frequencies are launched is referred to as the sweeping rate. This rate may be any value, including, but not limited to, milliseconds, seconds, and minutes. Preferably, the sweep rate is as rapid as practical for a particular resin. The uniformity in processing afforded by frequency sweeping, provides flexibility in how encapsulated IC chips or components are oriented within the microwave furnace. Maintaining each encapsulated component in precisely the same orientation is not required to achieve uniform processing.

The foregoing is illustrative of the present invention and is not to be construed as limiting thereof. Although a few exemplary embodiments of this invention have been described, those skilled in the art will readily appreciate that many modifications are possible in the exemplary embodiments without materially departing from the novel teachings and advantages of this invention. Accordingly, all such modifications are intended to be included within the scope of this invention as defined in the claims. In the claims, means-plus-function clause are intended to cover the structures described herein as performing the recited function and not only structural equivalents but also equivalent structures. Therefore, it is to be understood that the foregoing is illustrative of the present invention and is not to be construed as limited to the specific embodiments disclosed, and that modifications to the disclosed embodiments, as well as other embodiments, are intended to be included within the scope of the appended claims. The invention is defined by the following claims, with equivalents of the claims to be included therein.

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CLAIMS:

1. A method of surface mounting a microelectronic component to rapidly produce a microelectronic assembly having reduced residual stresses therein, said method comprising the steps of:

conductively securing a microelectronic component to a substrate surface;

encapsulating a portion of said microelectronic component and a portion of said substrate surface adjacent said microelectronic component with a curable resin; and

sweeping said curable resin with at least one range of microwave frequencies to selectively cure said encapsulating resin, thereby producing a microelectronic assembly having reduced residual stresses therein.

2. A method according to Claim 1 wherein said curable resin has a first coefficient of thermal expansion and said substrate has a second coefficient of thermal expansion, said second coefficient of thermal expansion greater than said first coefficient of thermal expansion.

3. A method according to Claim 1, wherein said curable resin is a thermosetting or thermoplastic resin.

4. A method according to Claim 1 wherein said at least one range of microwave frequencies is selected to heat said substrate to a first temperature and to heat said curable resin to a second temperature, wherein said first temperature is less than said second temperature.

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5. A method according to Claim 4 wherein said second temperature is between about 20% and about 50% greater than said first temperature.

6. A method according to Claim 1 wherein said at least one range of microwave frequencies is a plurality of ranges of microwave frequencies.

7. A method of surface mounting a microelectronic component to rapidly produce a microelectronic assembly having reduced residual stresses therein, said method comprising the steps of:

conductively securing an integrated circuit chip to a substrate surface;

encapsulating said integrated circuit chip and a portion of said substrate surface adjacent said integrated circuit chip with a curable resin, wherein said curable resin has a coefficient of thermal expansion between thermal expansion coefficients of said substrate and said integrated circuit chip; and

sweeping said curable resin with at least one range of microwave frequencies to selectively cure said encapsulating resin, said at least one range of microwave frequencies selected to heat said substrate to a first temperature and to heat said resin to a second temperature, wherein said first temperature is less than said second temperature, thereby producing a microelectronic assembly having reduced residual stresses therein.

8. A method according to Claim 7, wherein said curable resin is a thermosetting or thermoplastic resin.

9. A method according to Claim 7 wherein said second temperature is between about 20% and about 50% greater than said first temperature.

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10. A method according to Claim 7 wherein said at least one range of microwave frequencies is a plurality of ranges of microwave frequencies.

11. A method of surface mounting a microelectronic component to rapidly produce a microelectronic assembly having reduced residual stresses therein, said method comprising the steps of:

conductively securing an integrated circuit chip having an active surface to a substrate surface, wherein said integrated circuit chip active surface is in opposing spaced apart relation with said substrate surface;

providing a curable resin between said integrated circuit chip active surface and said substrate surface, wherein said resin is in contacting relation with said integrated circuit chip active surface and said substrate surface, wherein said curable resin has a coefficient of thermal expansion between thermal expansion coefficients of said substrate and said integrated circuit chip; and

sweeping said curable resin with at least one range of microwave frequencies to selectively cure said encapsulating resin, said at least one range of microwave frequencies selected to heat said substrate to a first temperature and to heat said resin to a second temperature, wherein said first temperature is less than said second temperature, thereby producing a microelectronic assembly having reduced residual stresses therein.

12. A method according to Claim 11, wherein said curable resin is a thermosetting or thermoplastic resin.

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13. A method according to Claim 11 wherein said second temperature is between about 20% and about 50% greater than said first temperature.

14. A method according to Claim 11 wherein said at least one range of microwave frequencies is a plurality of ranges of microwave frequencies.

15. A method according to Claim 11 further comprising the step of removing air entrapped within said curable resin prior to said step of sweeping said integrated circuit chip and substrate with at least one range of microwave frequencies.

16. A system for surface mounting a microelectronic component to rapidly produce a microelectronic assembly having reduced residual stresses therein, said system comprising:

means for conductively securing a microelectronic component to a substrate surface;

means for encapsulating a portion of said microelectronic component and a portion of said substrate surface adjacent said microelectronic component with a curable resin; and

means for sweeping said curable resin with at least one range of microwave frequencies to selectively cure said encapsulating resin, thereby producing a microelectronic assembly having reduced residual stresses therein.

17. A system according to Claim 16 wherein said means for sweeping said microelectronic component and substrate with at least one range of microwave frequencies comprises means for sweeping with a plurality of ranges of microwave frequencies.

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