

A BLADE STRUCTURE TO DIRECT PRECURSOR GASES FOR THE GROWTH
OF UNIFORM LARGE AREA TMDCS

Cross-Reference to Related Application

5 [0001] This application claims the benefit of priority of Singapore Patent Application No. 10202102089V, filed 2 March 2021, the content of it being hereby incorporated by reference in its entirety for all purposes.

Technical Field

10 [0002] The present disclosure relates to a device structurally configured to render a continuous layer of semiconducting material to form on a substrate.

Background

[0003] Transition metal dichalcogenides (TMDCs) in monolayer form or few-layer
15 forms are promising materials for next generation of low power electronics. A number of devices operable to demonstrate mechanically exfoliated monolayer or few-layer TMDCs may have shown attractive properties such as indirect-to-direct band gap transitions, strong spin-orbit coupling and valley polarization. These may have strong implications for applications ranging from low power electronics and opto-electronics
20 to quantum computing.

[0004] However, it remains difficult to grow a wafer-sized and highly uniform continuous monolayer TMDC film using traditional chemical vapour deposition (CVD) techniques due to the challenge of controlling growth kinetics for wafer size. In a traditional chemical vapour deposition process for producing such TMDC film, the
25 transition metal precursor tends to require a high temperature for sublimation and thus tends to be placed together with the substrate inside the main chamber at a high-temperature zone of the CVD furnace. The evaporation rate, distribution and amount of heated transition metal oxide source then play a considerable role on the growth uniformity of the TMDC film. Good control of these factors is particularly challenging
30 for transition metal precursors (e.g. WO_x wherein W refers to a transition metal and x may be an integer) requiring very high temperature to achieve a substantial vapour pressure for epitaxial growth of TMDCs (e.g. WS_2 , WSe_2) to happen. Too high a vapour

pressure tends to be difficult for reproducible growth control, while too low vapour pressure renders undesirable small grain growth.

[0005] More recently, a metal-organic CVD (MOCVD) process was developed to provide a constant precursor supply and increase the scalability for the growth of TMDCs thin films. The liquid precursors with high equilibrium vapour pressure used in MOCVD perhaps allow more reliable control in terms of their flow rate and dose with bubblers and mass flow controllers. However, growth of the monolayer WS₂ and MoS₂ films takes an undesirably long time (more than a day for monolayer growth) and the grain size of WS₂ films is undesirably small (less than several tens of nm) with random orientation. Despite this, large and uniform grain growth uniformity at the wafer scale remains an outstanding problem for the general growth of TMDCs and in particular for those based on high temperature sublimation sources such as those required to grow tungsten-based TMDCs (i.e. WO_x).

[0006] There is thus a need to provide for a solution that addresses one or more of the limitations mentioned above. The solution should at least provide for a device configured to render a continuous monolayer of semiconducting material on a wafer substrate.

Summary

[0007] In a first aspect, there is provided for a device structurally configured to render a continuous layer of semiconducting material to form on a substrate, the device includes:

one or more blade structures, wherein each of the one or more blade structures have (i) one end which a precursor source is to be placed proximal to and (ii) the other end spaced apart from the substrate; and

a supporting structure arranged peripheral to the one or more blade structures for supporting the substrate to be placed thereon or therewith,

wherein the one or more blade structures are arranged to define one or more spaces which direct vapor produced from the precursor source toward the other end of each of the one or more blade structures, and

wherein (i) the supporting structure, (ii) the substrate to be placed thereon, and (iii) the one or more blade structures define an area which confines the vapor to the

area, thereby having the continuous layer of semiconducting material formed on a surface of the substrate which is adjacent to the area.

Brief Description of the Drawings

[0008] The drawings are not necessarily to scale, emphasis instead generally being placed upon illustrating the principles of the present disclosure. In the following description, various embodiments of the present disclosure are described with reference to the following drawings, in which:

[0009] FIG. 1A is a schematic showing a side view of the device of the present disclosure, wherein the blade structures and supporting ledge are shown.

[0010] FIG. 1B is a schematic showing a top-down view of the device of the present disclosure, wherein the blade structures and supporting ledge are shown.

[0011] FIG. 1C is a photo of the 1" x 1" prototype device developed. 1" denotes for 1 inch.

[0012] FIG. 2 is a schematic showing the blade structures placed between the precursor and substrate. The arrows depict the flow of the gaseous precursor.

[0013] FIG. 3A is a photo showing an original substrate sample subject to WS₂ formation thereon without using the present device.

[0014] FIG. 3B shows the substrate sample of FIG. 3A in grayscale.

[0015] FIG. 3C shows the substrate sample of FIG. 3A in enhanced contrast.

[0016] FIG. 3D is a photo showing an original substrate sample subject to WS₂ formation thereon using the present device.

[0017] FIG. 3E shows the substrate sample of FIG. 3D in grayscale.

[0018] FIG. 3F shows the substrate sample of FIG. 3D in enhanced contrast.

[0019] FIG. 3G is an optical microscopy (OM) image of the region identified by the dotted-lined square in FIG. 3C.

[0020] FIG. 3H is an optical microscopy image of the region identified by the dotted square in FIG. 3F.

[0021] FIG. 3I shows the photoluminescence (PL) spectra of the WS₂ formed in the region as shown in FIG. 3H.

[0022] FIG. 3J shows the Raman spectrum of the WS₂ formed in the region as shown in FIG. 3H.

[0023] FIG. 4A is a schematic of a trap area.

[0024] FIG. 4B is a photo showing the structures in the present device, using silicon blocks to provide a spacing of 6 mm, the dotted-lined region represents the substrate position during growth of a semiconducting material.

5 [0025] FIG. 4C shows an enhanced contrast photo of 2 samples grown using the same device structure displayed in FIG. 4B.

[0026] FIG. 4D is an OM image of the region identified by the dotted-lined square in FIG. 4C showing the edge of film formation.

[0027] FIG. 4E is a magnified image of the discontinuous WS₂ portion shown in FIG. 4D, wherein grains over 100 μm can be observed.

[0028] FIG. 4F is a Raman spectrum plot of the WS₂ of one of the samples of FIG. 4C.

[0029] FIG. 5A is a schematic of the test carried out combining blade structures and trap area structure.

[0030] FIG. 5B is a photo of a 1 x 1 cm sample grown using the structure of FIG. 5A.

15 [0031] FIG. 5C is an enhanced color contrast image of FIG. 5B.

[0032] FIG. 5D shows the OM image of a continuous WS₂ film grown on a cleaved sapphire sample. The dotted-lined region indicates the area covered by the supporting ledge in which the WS₂ becomes discontinuous.

[0033] FIG. 5E is a Raman spectrum confirming the presence of WS₂ on the brighter area highlighted in FIG. 5D.

[0034] FIG. 5F is a PL spectrum confirming the presence of WS₂ on the brighter area highlighted in FIG. 5D.

[0035] FIG. 6 shows an embodiment of the present device, depicting its side view.

[0036] FIG. 7A shows the blade structures arranged in parallel from a top-down view.

25 [0037] FIG. 7B shows a blade structure having a spiral configuration from a top-down view.

[0038] FIG. 7C shows blade structures arranged in concentric circles from a top-down view.

[0039] FIG. 8 shows an embodiment of the present device having a modified shower head structure from a side view.

[0040] FIG. 9 shows that traditional chemical vapor deposition (CVD) results in non-uniform vapor flow even with use of additional argon gas carrier. Grain size reduces as

distance from TMDC source increases (compare images I to III), demonstrating difficulty of achieving uniform wafer-size processing in such a manner.

[0041] FIG. 10 compares the grain size obtained via traditional methods of metal-organic CVD (MOCVD), atomic layer deposition (ALD), sulfurization (increase sulfur supply), all of which led to small grain size.

[0042] FIG. 11 depicts the advantages afforded by the present device in terms of uniformity of crystal growth on a substrate and the grain size of crystals grown.

[0043] FIG. 12 depicts the density of growth coverage of a TMDC (bounded by the dotted line) over a 1 cm² sapphire wafer (in top left image). The top right image is an optical microscopy image of the selected area (of top left image) of the grown TMDC subjected to quality assessment by photoluminescence (PL) measurements. The bottom left image shows a PL integrated intensity map and the bottom right image is a representation PL linewidth map. These PL maps provide a proxy assessment of achievable growth uniformity using the device of the present disclosure.

[0044] FIG. 13A depicts the increase of a monolayer TMDC growth coverage (see boxed areas in inset corresponding to each data point in the left image plot) using a traditional crucible (no blade structure, i.e. only end supports for the substrate), and two versions of blade structures Design V1 (see FIG. 4A, 6 mm wide blade) and Design V2 (see FIG. 5A, 1 mm narrow blade). The coverage percentage of 20% and 14% achieved respectively using the traditional crucible and Design V1 were lower than the 85% TMDC monolayer coverage grown on a substrate using Design V2. Said differently, using the present device having blades structures of Design V2, a significant improvement to 85% growth coverage was achieved. This also advantageously shows that different monolayer coverage can be attained by configuring the blade structure(s) of the present device. The optical microscopy image on the right shows a typical growth boundary on the substrate that was placed proximal to the supporting structure (e.g. see “support” in FIG. 13B or the “ledges” in FIG. 6A or the supporting ledge in FIG. 5A for understanding). Directly at the support, growth is inhibited due to masking of the substrate’s surface by the support, as the substrate is placed on the support. Moving away from the support, continuous uniform monolayer TMDC film formation is observed.

[0045] FIG. 13B shows the present device with more blades configured based on the “Design V2” with 1 mm wide blades described for FIG. 13A. This enables supporting large substrates.

[0046] FIG. 14 shows the vapor flow for a device without the blade structures. The TMDC material accumulated only at edges of the substrate.

[0047] FIG. 15A is a plot of effective mass against mobility (also current density) comparing materials of silicon, tungsten diselenide (WSe_2) and tungsten disulfide (WS_2). Variation in the color scale denotes for the current density in the plot.

[0048] FIG. 15B is a plot of energy against delay highlighting the salient electrical properties of various transistors built based on few layer WS_2 .

Detailed Description

[0049] The following detailed description refers to the accompanying drawings that show, by way of illustration, specific details and embodiments in which the present disclosure may be practised.

[0050] Features that are described in the context of an embodiment may correspondingly be applicable to the same or similar features in the other embodiments. Features that are described in the context of an embodiment may correspondingly be applicable to the other embodiments, even if not explicitly described in these other embodiments. Furthermore, additions and/or combinations and/or alternatives as described for a feature in the context of an embodiment may correspondingly be applicable to the same or similar feature in the other embodiments.

[0051] The present disclosure relates to a device structurally configured to render a continuous layer of semiconducting material to form on a substrate. The device may be termed herein a “crucible”, as it houses one or more blade structures which direct gas flow to a substrate for forming the semiconducting material on the substrate. The substrate may be placed on a supporting structure (also termed herein a supporting ledge).

[0052] Traditionally, most methods to promote crystals growth (e.g. growth of TMDC material) involve CVD, positioning of precursors and zone heating control in a deposition chamber. Other methods may involve pre-coating the substrate with growth-promoting precursor molecules which introduce undesirable contamination. The

present device circumvents such limitations. As mentioned above, the present device includes one or more blade structures configured to direct vapor flow to an area in close proximity to the substrate so as to enable local control over homogeneity of growth without introducing additional growth promoting agents. This simplifies the growth process and reduce undesirable side effects from growth promoting agents.

[0053] Traditionally, there may be four methods for the deposition of TMDCs - (1) sulfurization (increase sulfur supply), (2) MOCVD, (3) ALD and (4) traditional CVD. In general, methods (1) to (3) have been used for large scale synthesis of TMDCs because they tend to be easily scalable at the wafer scale. However, that scalability comes at the expense of resulting in undesirable small grain size (normally smaller than $\sim 1 \mu\text{m}$). As for CVD, it may be traditionally a more preferred method that is restricted to research because of the possibility to grow large grains/single crystal but the CVD process tends to suffer from a poor uniformity across large areas due to the difficulty of controlling the high temperature metal precursors required for the process. In particular, chalcogenides based on tungsten remain a major challenge in terms of the uniformity using the traditional CVD process due to the low vapour pressure even under the temperatures normally used for other TMDCs such as MoS_2 ($\sim 800^\circ\text{C}$). Reportedly, traditional CVD with no modifications resulted in decent grain size but poor uniformity across the substrate. A modified version of the CVD process separating the chalcogenide source from the metal source largely improves the uniformity, but unfortunately did not appear feasible for tungsten-based chalcogenides. In the present device, conveniently, the blade structures can be configured so as to have the metal source (an example of the precursor) and the substrate positioned with the blade structures in between to direct the vapor flow toward the substrate, rendering better uniformity and increased grain size. The examples herein demonstrate the feasibility of the present device for use with low vapor pressure sources such as the ones used for tungsten-based chalcogenides, in fact, the present device can be further used with other chalcogenide materials that require sources having much higher vapor pressure such as molybdenum-based chalcogenides for forming a crystalline TMDC monolayer on a substrate.

[0054] Details of various embodiments of the present device and advantages associated with the various embodiments of the present device are now described below. Where

the embodiments and advantages of the present device have been described in the example section further hereinbelow, they shall not be reiterated for brevity.

[0055] In the present disclosure, there is provided a device structurally configured to render a continuous layer of semiconducting material to form on a substrate. The continuous layer may be a continuous monolayer. The term “monolayer” herein refers to a single layer formed of atoms or molecules that do not stack on each other (i.e. reside in a single plane).

[0056] The device can include one or more blade structures, wherein each of the one or more blade structures have (i) one end which a precursor source is to be placed proximal to and (ii) the other end spaced apart from the substrate. The present device can include a supporting structure arranged peripheral to the one or more blade structures for supporting the substrate to be placed thereon or therewith. In embodiments where the supporting structure supports the substrate to be placed therewith (e.g. see FIG. 8), the supporting structure is configured to have or hold the substrate in place and proximal to the one or more blade structures (rather than to have the substrate supported away from the one or more blade structures).

[0057] In various embodiments, the one or more blade structures can be arranged to define one or more spaces which direct vapor produced from the precursor source toward the other end of each of the one or more blade structures.

[0058] In various embodiments, (i) the supporting structure, (ii) the substrate to be placed thereon, and (iii) the one or more blade structures define an area which confines the vapor to the area, thereby having the continuous layer of semiconducting material formed (from the vapor) on a surface of the substrate that is adjacent to the area.

[0059] In various embodiments, the one or more blade structures are shorter in height compared to the supporting structure.

[0060] In various embodiments, the one or more blade structures are arranged apart to define the one or more spaces which direct the vapor toward the area.

[0061] In various embodiments, each of the one or more spaces can have a width ranging from 2 mm to 8 mm, 2 mm to 7 mm, 2 mm to 6 mm, 3 mm to 8 mm, 3 mm to 7 mm, 3 mm to 6 mm, etc. The one or more spaces are not limited to these dimensions and can be configured to cater to vapor flow requirements. The one or more spaces can be equal or different in width.

[0062] In certain non-limiting embodiments, the one or more blade structures may include one blade structure arranged in parallel with respect to the supporting structure. In certain non-limiting embodiments, the one or more blade structures may include two blade structures arranged in parallel. In certain non-limiting embodiments, the one or more blade structures may include a vertically erected spiral structure which emanates from a point and revolves around an axis of the point at a constant or continuously varying distance while remaining parallel to the axis. In certain non-limiting embodiments, the one or more blade structures may include vertically erected structures arranged in concentric circles.

10 [0063] In various embodiments, each of the one or more blade structures has a thickness of at least 1 mm, 1 mm to 6 mm, 1 mm to 5 mm, 1 mm to 4 mm, 1 mm to 3 mm, 1 mm to 2 mm, etc. In various embodiments, the one or more blade structures can have a height ranging from 2 mm to 6 mm, 2 mm to 5 mm, 3 mm to 6 mm, 3 mm to 5 mm, etc. The thickness and height of the one or more blade structures are not limited to these dimensions. The one or more blade structures are vertically shorter than the supporting structure to define the area which confines the vapor generated from the precursor source.

[0064] In various embodiments, the one or more blade structures and the supporting structure render the area to have a height of at least 0.2 mm, 0.3 mm, 0.4 mm, 0.5 mm, 1 mm, 2 mm, etc. Said differently, the height of the area can be defined by the difference in height between a blade structure and the supporting structure.

20 [0065] In various embodiments, the supporting structure defines an enclosure surrounding the one or more blade structures. In certain non-limiting embodiments, the enclosure, when viewed from top-down, is a circular enclosure or a four-sided enclosure.

[0066] In certain non-limiting embodiments, the supporting structure may include two intersecting supporting elements configured within the enclosure, wherein the two intersecting supporting elements have the same height as the supporting structure. In certain non-limiting embodiments, the two intersecting supporting elements can be arranged perpendicular to each other and each of the two intersecting supporting elements has one end adjoined to the supporting structure. For instance, the two

intersecting supporting elements can have two opposing ends, and each of the two opposing ends can be adjoined to the supporting structure (e.g. see FIG. 7C).

[0067] In various embodiments, the present device may further include a shower head arranged proximal to the one or more blade structures. The shower head is operable to
5 disperse the vapor through the one or more spaces toward the area.

[0068] In various embodiments, the precursor source can include (i) a transition metal oxide and a chalcogen or (ii) a transition metal halide and a hydrogen chalcogenide. Non-limiting examples of the transition metal oxide include WO_3 and MoO_3 . Non-limiting examples of the chalcogen include sulfur, selenium, tellurium. A non-limiting
10 example of the transition metal halide include WF_6 . A non-limiting example of the hydrogen chalcogenide include H_2S . The precursor source can be a solid, for example, the transition metal oxide and chalcogen can be solid.

[0069] In various embodiments, the present device can be formed of sapphire, quartz, graphite, a carbide, or a nitride. In various embodiments, the one or more blade
15 structures and the supporting structure are formed of any of aforesaid materials. The graphite can be a pyrolytic graphite. The present device, that is, the one or more blade structures and/or the supporting structure can be formed of any material (such as a ceramic) capable of withstanding a temperature of 1000°C or higher. The material should be structurally stable, do not degrade, do not produce contaminants or be toxic
20 at such temperatures (whether higher or lower).

[0070] In various embodiments, the semiconducting material can include or may be a transition metal dichalcogenide. Non-limiting examples of the transition metal dichalcogenide include MoS_2 , WS_2 , MoSe_2 , WSe_2 , MoTe_2 , WTe_2 , MoSeS , WSeS , etc.

[0071] The word “substantially” does not exclude “completely” e.g. a composition
25 which is “substantially free” from Y may be completely free from Y. Where necessary, the word “substantially” may be omitted from the definition of the present disclosure.

[0072] In the context of various embodiments, the articles “a”, “an” and “the” as used with regard to a feature or element include a reference to one or more of the features or elements.

[0073] In the context of various embodiments, the term “about” or “approximately” as
30 applied to a numeric value encompasses the exact value and a reasonable variance.

[0074] As used herein, the term “and/or” includes any and all combinations of one or more of the associated listed items.

[0075] Unless specified otherwise, the terms “comprising” and “comprise”, and grammatical variants thereof, are intended to represent “open” or “inclusive” language such that they include recited elements but also permit inclusion of additional, unrecited elements.

Examples

[0076] The present disclosure relates to a device having uniquely configured structures, wherein the device is configurable between a substrate and a precursor source (e.g. a metal precursor) for forming a material on the substrate. The structure can at least render (i) uniform gas flow of the sublimated source material (precursor source) to the substrate and (ii) help to trap the gas for formation of large grains on the substrate during growth of the material. The material can be any semiconducting material. The material can be any transition metal dichalcogenide (TMDC). Non-limiting examples of the transition metal dichalcogenide include tungsten disulfide, tungsten diselenide, tungsten ditelluride, molybdenum disulfide, molybdenum diselenide, and/or molybdenum ditelluride.

[0077] The present device is described in further details, by way of non-limiting examples, as set forth below.

[0078] Example 1: Structure of Present Device

[0079] FIG. 1A to 1C show a non-limiting example of the present device. It can be seen that the blade structures (herein termed “blades” for brevity) should be arranged proximal to a precursor (also termed “precursor source”) while the trap area (herein termed “area” for brevity) should be proximal to (i.e. face) the substrate. The precursor source can include, for example, (i) a transition metal oxide and a chalcogen or (ii) a transition metal halide and a hydrogen chalcogenide. Non-limiting examples of the transition metal oxide include WO_3 and MoO_3 . Non-limiting examples of the chalcogen include sulfur, selenium, tellurium. A non-limiting example of the transition metal halide include WF_6 . A non-limiting example of the hydrogen chalcogenide include H_2S . The precursor can be a solid, for example, the transition metal oxide and chalcogen can be solid. Where the precursor source includes a solid transition metal oxide, the

precursor source may be placed distal from the substrate (e.g. at least about 3 mm from the substrate to allow vapor generated from the precursor source to flow toward the substrate). Hence, the supporting structure and/or the one or more blade structures may have a height of 3 mm or more. If the precursor source is already in the gaseous form, e.g. WF_6 and H_2S , there may be no height restriction but the vapor flow of the gaseous precursor source has to be directed toward the substrate via the one or more spaces defined by the arrangement of the one or more blade structures. One non-limiting example where a gaseous precursor source can be applied is through a showerhead as shown in FIG. 8.

10 **[0080]** Where the precursor used is a solid, the precursor may be heated to generate its vapor form. The temperature to generate vapor from a solid precursor depends on the solid precursor. For example, to generate vapor of WO_3 and MoO_3 , a temperature in the range of 800 to 1000°C may be applied.

15 **[0081]** The blades help direct flow of the vapor towards the substrate as denoted by the arrows in FIG. 2 and the trap area (underneath the substrate) concentrates (i.e. confined) the vapour in proximity of the substrate to allow the formation of large grains (e.g. crystals of a TMDC). The blades advantageously direct the vapor toward the area which the components in the vapor of the precursor source may react to form a monolayer of TMDC on the substrate. As described above, the vapor may be from a gaseous precursor or generated by heating a solid precursor.

20 **[0082] Example 2: Effect from Structure of Present Device**

[0083] In order to investigate and demonstrate the effect conferred by the device, including effect arising from the blades, samples were prepared using devices with and without the blades (no trap area is present without the blades).

25 **[0084]** For the sample prepared without the blades, only grey areas with varying uniformity are observed at the lateral borders of the sample (see FIG. 3C). OM images of the samples where the grey area is observed revealed the nucleation of WS_2 but a continuous film was not obtained.

30 **[0085]** Meanwhile, using the present device (see FIG. 1C), there was an obvious increase (over 80%) in the coverage of the substrate from the colour contrast test (FIG. 3D). OM images of the film growth using the device with blade structures showed a

more homogeneous distribution of WS₂ in the film formed and there were no obvious holes observed for the film formed in the central area of the substrate (FIG. 3H).

[0086] Additional Raman data displaying the spectra of WS₂ with a separation of 65 cm⁻¹ between A1g and E2g (FIG. 3J) and a large photoluminescence peak located at 618 nm wavelength (FIG. 3I) taken from region identified in FIG. 3H are the fingerprint of monolayer WS₂. In FIG. 3J, A1g and E2g denote the peaks in the Raman spectrum that relate respectively to the out-of-plane vibrations and in-plane vibrations of the WS₂ TMDC monolayer crystal.

[0087] As can be seen in FIG. 1A, the device includes a trap area. An objective of the trap area is to allow a continuous full film formation across the surface of substrate exposed to the trap area. FIG. 4A shows that by keeping a small gap (0.5 mm), that is enough to allow the diffusion of the precursor source between 1-2 mm just right above of the blade (FIG. 4C and 4D, also FIG. 5A). This trap area allows the full film formation across the substrate.

[0088] In addition, through the present device, the grain size of the WS₂ material formed on the substrate's surface right above the blade largely increased (FIG. 4E). The crystal quality was also assessed by Raman/PL characterization. It is also shown that by further combining the blades with the trap area, a dense coverage of large TMDC grains can be obtained while preserving a good quality film assessed by the uniformity of the PL and Raman (FIG. 5E and 5F). The film only becomes discontinuous close to the supporting ledge (dotted-lined square in FIG. 5D).

[0089] By using the present device containing aforesaid blade structures, the substrate size tested ranged from 25 x 5 mm to 25 x 15 mm, which demonstrates scalability of the present device. These dimensions are non-limiting and the present device may be scaled accordingly to applications' need.

[0090] **Example 3: Dimensions of Blade Structure**

[0091] FIG. 6 shows a schematic of one embodiment of the present device, depicting the side view to indicate parameters to be considered for the blade structure. Z1 and Z2 are the trap area and blade height, respectively. In one example, Z1 was set to 0.4 mm while Z2 was 2 mm. it should be noted that in preliminary tests, a Z1 of 0.5 mm was used to test effectiveness the trap area. B1 and S1 are the blade thickness and blade spacing, respectively. One of the current prototype uses B1=1 mm and S1=5 mm.

Additional tests carried out using an additional support to reduce S1 up to 2 mm also showed good results.

[0092] In the present examples, the results are based on the device as shown and the device's structural dimensions were configured based on several rounds of investigations. Nevertheless, the structural configuration and dimension of the structures in the present device can be simulated or adjusted through multiphysics simulation (such as Comsol/Ansys), such as to configure the size and separation of the blades, so as to be more expedient when developing the device to work with different process systems.

[0093] In other non-limiting embodiments, the blade structure can be configured as shown in FIG. 7A. In addition, other geometries that can be configured to direct the flow of vapor to the substrate are presented in FIG. 7B and 7C. For constructing the crucible (present device), two non-limiting examples of materials were tested - quartz and sapphire. The present device can be formed from any other suitable materials depending on the application which the present device is to be used, such as graphite, carbides or nitrides that can withstand the process temperature and are inert to the precursors used.

[0094] Example 4: Summary

[0095] The present device may be deemed a wafer crucible having blade structures configurable to be inserted between the precursor and a substrate. The present device is configured especially for sources with low vapor pressure to direct and concentrate the flow near the substrate. In this way, advantageously, the present device improves the uniformity (when used for a CVD process) of TMDCs for large area growth. Application of the present device can be extended to any other compound materials that use precursor sources with higher vapor pressure by increasing or decreasing the height (Z1, Z2, S1, B1) of the structure accordingly. Similarly, the structure can be modified to redirect the flow on gas phase sources (shower head) for other growth process such as MOCVD and ALD (see FIG. 8).

[0096] While the present disclosure has been particularly shown and described with reference to specific embodiments, it should be understood by those skilled in the art that various changes in form and detail may be made therein without departing from the spirit and scope of the present disclosure as defined by the appended claims. The

scope of the present disclosure is thus indicated by the appended claims and all changes which come within the meaning and range of equivalency of the claims are therefore intended to be embraced.

CLAIMS

1. A device structurally configured to render a continuous layer of semiconducting material to form on a substrate, the device comprising:

one or more blade structures, wherein each of the one or more blade structures have (i) one end which a precursor source is to be placed proximal to and (ii) the other end spaced apart from the substrate with a vertical gap between the other end and the substrate; and

a supporting structure arranged peripheral to the one or more blade structures for supporting the substrate to be placed thereon or therewith,

wherein the one or more blade structures are arranged to define one or more spaces which direct vapor produced from the precursor source toward the other end of each of the one or more blade structures, and

wherein (i) the supporting structure, (ii) the substrate to be placed thereon, and (iii) the one or more blade structures define an area which confines the vapor to the area, thereby having the continuous layer of semiconducting material formed on a surface of the substrate which is adjacent to the area.

2. The device of claim 1, wherein the one or more blade structures are shorter in height compared to the supporting structure.

3. The device of claim 1 or 2, wherein the one or more blade structures are arranged apart to define the one or more spaces which direct the vapor toward the area.

4. The device of claim 3, wherein each of the one or more spaces has a width ranging from 3 mm to 6 mm.

5. The device of any one of claims 1 to 4, wherein the one or more blade structures comprise:

one blade structure arranged in parallel with respect to the supporting structure;

two blade structures arranged in parallel;

a vertically erected spiral structure which emanates from a point and revolves around an axis of the point at a constant or continuously varying distance while remaining parallel to the axis; or

vertically erected structures arranged in concentric circles.

6. The device of any one of claims 1 to 5, wherein each of the one or more blade structures has a thickness of at least 1 mm.

7. The device of any one of claims 1 to 6, wherein the one or more blade structures have a height ranging from 3 mm to 5 mm.

8. The device of any one of claims 1 to 7, wherein the supporting structure defines an enclosure surrounding the one or more blade structures.

9. The device of claim 8, wherein the enclosure, when viewed from top-down, is a circular enclosure or a four-sided enclosure.

10. The device of claim 8 or 9, wherein the supporting structure comprises two intersecting supporting elements configured within the enclosure, wherein the two intersecting supporting elements have the same height as the supporting structure.

11. The device of claim 10, wherein the two intersecting supporting elements are arranged perpendicular to each other and each of the two intersecting supporting elements has two opposing ends adjoined to the supporting structure.

12. The device of any one of claims 1 to 11, further comprising a shower head arranged proximal to the one or more blade structures, wherein the shower head is operable to disperse the vapor through the one or more spaces toward the area.

13. The device of any one of claims 1 to 12, wherein the precursor source comprises:

- (i) a transition metal oxide and a chalcogen; or
- (ii) a transition metal halide and a hydrogen chalcogenide.

14. The device of any one of claims 1 to 13, wherein the one or more blade structures and the supporting structure are formed of sapphire, quartz, graphite, a carbide, or a nitride.

15. The device of any one of claims 1 to 14, wherein the semiconducting material comprises a transition metal dichalcogenide.