

LASER PROCESSING METHOD AND APPARATUS FOR FORMING A LAYER OF MATERIAL

TECHNICAL FIELD

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The present invention relates to a laser processing method and apparatus. In particular, it relates to a laser processing method and apparatus for forming a layer of material onto a substrate.

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BACKGROUND

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The technology to form a layer of material onto a substrate has a wide variety of applications. In the electronics industry, metal traces are formed onto a substrate to provide electrical conductivity. In one application, the manufacturing and repair of certain microelectronics and/or optoelectronics components require the formation of electrically conductive lines or paths onto the surface of a substrate. For the repair of thin-film transistor – liquid crystal display (TFT-LCD) panels, a conductive path or circuit may be deposited on the transparent substrate to re-establish connectivity of a defective circuit.

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For example, US Patent No. 4,880,959 discloses a laser induced chemical vapor deposition (LCVD) process to interconnect thin-film electrical circuits. In an LCVD process, photo-thermal or photo-decomposition of an organometallic compound in the gas phase over the working substrate is required. The working substrate should be placed in a sealed chamber filled with organometallic gas before the deposition can proceed. However, preparation of the process is cumbersome, and the LCVD process has a low production throughput. In addition, organometallic compounds are toxic and may cause environmental problems. These and other problems have prevented the LCVD process from being widely adopted in the industry.

Laser ablation deposition (LAD) has been proposed to form a thin film

onto a substrate without the presence of chemical compounds. U.S. Patent. No. 5,173,441 discloses a laser ablation deposition process for semiconductor manufacture. In this method, a source substrate and a target substrate are mounted in close proximity to one another within a vacuum chamber. A laser beam is scanned in a programmed sequence or selected pattern through a transparent target substrate and onto a metallic film formed on the source substrate. Ablation of the metal film and deposition onto the target substrate may be controlled by the laser being focused directly at the metal film on the source substrate, and by the selection of a source substrate having a suitable thermal conductivity. The process may be used to fabricate photomask, electro-optic, and acousto-optic devices, transducers, and integrated circuits on insulator substrate.

Fig. 1-A and Fig. 1-B illustrate the "writing" LAD process. The source substrate 1 consists of a thin film 2 of the desired metal to be deposited, coated by conventional methods on a support substrate 3 that has been selected to possess certain thermal and mechanical properties. The workpiece or working substrate 4, which is transparent to the wavelength of the laser used, is placed in close proximity to the source substrate 1 with the surface to be deposited facing the thin film 2 of the source substrate 1. A laser beam 10 is directed onto the thin metal film 6, which is a portion of thin film 2, through the transparent working substrate 4 to vaporize the metal film 6. The resulting plume 8 of metallic atoms and ions expands away from the source substrate 1 and condenses on the cooler surface 5 of the working substrate 4, to form the deposit 7.

By scanning the source substrate with overlapping laser spots, lines, paths, traces or films deposit can be formed. The paths or traces formed by this method are generally spread out in an area wider than the laser beam focus diameter. The quality of the deposition is therefore highly dependent on the degree of overlap of the laser irradiation. Because of the overlap, it is difficult to obtain a smooth and continuous deposition, with precise size and

intervals between two adjacent traces, hence it is difficult to control the shape and dimension of the formed thin film traces. Further, as plume 8 is spread out onto working substrate 4, the line, path or trace formed does not have a clear and sharp edge.

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Thus, there is a need to provide a laser processing method and apparatus for forming thin film traces and/or lines with controlled quality so that electronic circuits with high dimensional and positional accuracy may be fabricated.

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SUMMARY

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According to one aspect of the present invention, there is provided a method for forming a layer of material onto a substrate at a target region. A laser beam is directed onto a material source through the substrate so that to generate an induced material from the material source. The induced material then deposits onto the substrate to form the layer of material, and the laser beam removes the layer of material deposited on a border region which is outside the target region.

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In one embodiment, the laser beam passes through the substrate at an intersecting region overlapping the border region such that the laser beam ablates the border region to remove the layer of material deposited onto the border region.

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According to another aspect of the present invention, there is provided an apparatus for forming a layer of material onto a substrate at a target region. The apparatus comprises a laser source for generating a laser beam, and an optical system for directing the laser beam onto a substrate. The laser beam generates an induced material from the material source to deposit onto the

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substrate to form the layer of material, and the laser beam removes the layer of material deposited outside the target region.

BRIEF DESCRIPTION OF THE DRAWINGS

5 These and other aspects and advantages of the present invention will be described in detail with reference to the accompanying drawings, in which:

Figs. 1A and 1B are schematic drawings showing prior art laser forming method;

10 Figs. 2A, 2B and 2C are schematic drawings showing a laser forming method according to one embodiment of the present invention;

Figs. 3A, 3B and 3C are schematic drawings showing a laser forming method according to another embodiment of the present invention;

15 Fig. 4A is a schematic diagram showing a laser processing apparatus according to one embodiment of the present invention;

20 Figs. 4B and 4C are top views of a mask for controlling the laser beam of the apparatus shown in Fig. 4A;

Figs. 5A – 5D are schematic diagrams showing a layer of material formed onto a substrate according to various embodiments of the present invention;

25 Fig. 6 is a schematic diagram showing a laser processing apparatus according to another embodiment of the present invention;

30 Fig. 7 is a schematic diagram showing a laser processing apparatus according to a further embodiment of the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

As shown in Figs. 2A, 2B and 2C, a method of forming a layer of material onto a target region of a substrate according to one embodiment of the present invention is provided. A laser beam 210 is directed onto a material source, for example a source substrate 220, by passing through a working substrate 230 disposed adjacent to source substrate 220. Laser beam 210 irradiates source substrate 220 at one surface onto which a source material layer 222 is provided, for example, by laminating, sputtering, plating, spin-coating or Chemical Vapor Deposition (CVD).

Laser beam 210 may be a pulsed laser, having a wavelength between the ultraviolet and the infrared regions. In one particular example, laser beam 210 may have a wavelength of 355 nm or 532 nm. Source material layer 222 may be a metal, metal oxide, alloy, superconductor or semiconductor material. Working substrate 230 is made of laser-transmissible material having small absorption cross-section at the wavelength of laser beam 210 to allow most of the laser energy to pass through without substantial absorption. Working substrate 230 may be made of quartz, glass, sapphire, polymer or ceramic.

Laser beam 210 is provided with an energy level and fluence greater than the ablation threshold of source material layer 222. Upon irradiation, source material layer 222 is heated up rapidly, vaporized and generates an induced material or plume 224 which deposits onto the bottom surface of working substrate 230. Induced material or plume 224 then forms a layer of material 232 on substrate 230.

Process parameters such as laser fluence, pulse duration, and the distance between source substrate 220 and working substrate 230 are controlled to deposit the layer of material 232 onto a target region 230a of the working substrate 230. For purposes of illustration, the layer of material 232 is formed onto the bottom surface of working substrate 230 covering the target.

region 230a as well as border region 230b, adjacent to target region 230a, as shown in Fig. 2B.

5 In the deposition process, laser beam 210 passes through working substrate 230 at an intersecting region 230d of the bottom surface. Intersecting region 230d is a portion of working substrate 230 at the bottom surface through which laser beam passes, which is determined by the diameter and incident angle of laser beam 210 and the thickness of working substrate 230. According to one embodiment of the present invention, laser beam 210 is
10 positioned such that intersecting region 230d overlaps one of the border regions, for example border region 230b, as shown in Fig. 2B. By this arrangement, laser beam 210 ablates and vaporizes the portion of the layer of material 232 deposited on border region 230b. As a result, the portion of the layer of material 232 which are under the exposure of laser beam 210 is
15 removed from working substrate 230, resulting in the layer of material 232 remaining at the target region 230a with a clear and sharp edge profile 232b, as shown in Fig. 2C.

20 According to another embodiment of the present invention, as shown in Figs. 3A, 3B and 3C, a second laser beam 310 may be provided, having the same properties of the first laser beam 210, and is directed onto source substrate 220 through working substrate 230. Second laser beam 310 intersects the bottom surface of working substrate 230 at a second intersecting region 230e, which overlaps border region 230c. By this arrangement, second
25 laser beam 310 ablates and vaporizes the portion of the layer of material 232 deposited on border region 230c.

30 As a result, the portion of the layer of material 232 that is under the exposure of second laser beam 310, is removed from working substrate 230. Through the effects of first and second laser beams 210 and 310, the layer of material 232 remaining at the target region 230f has a clear and sharp edge profile 232b, 232c, and a precise dimension or width controlled by first and

second laser beams 210 and 310, as shown in Fig. 3C. One exemplary continuous and uniform deposited layer profile formed by the above method has a thickness of about several nanometers (nm) to several microns, and a width of about several microns.

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As shown in Fig. 4A, an apparatus 400 for forming a layer of material onto a working substrate is provided, according to one embodiment of the present invention. Apparatus 400 comprises a laser source 410 for generating a laser beam 412. Apparatus 400 further comprises an optical system having a beam attenuator 420, a mask 430, a shutter 440, a mirror 450, and an objective lens 460. Beam attenuator 420 is disposed adjacent to laser source 410 to control the fluence of laser beam 412. Mask 430 is provided next to attenuator 420 to control the profile of laser beam 412. Further directed by shutter 440, mirror 450 and objective lens 460, laser beam 412 arrives and irradiates material source 220, through working substrate 230. Material source 220 and working substrate 230 are supported by a holder, such as an X-Y stage 490. A controller 470 is provided to control the operations of attenuator 420, mask 430, shutter 440 and X-Y stage 490.

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In one embodiment as shown in Fig. 4B, mask 430 has a laser-blocking portion 432 for blocking part of laser beam 412 from passing through, and a laser-passing portion 434 adjacent to first portion 432 for allowing another part of the laser beam 412 to pass through. In this embodiment, one part of laser beam 412 is allowed to pass through laser-passing portion 434 to irradiate material source 220 to deposit the layer of material onto working substrate 230, and to remove the part of layer of material under the exposure of the laser beam from the border region 230b of working substrate 230, as illustrated above in conjunction with Figs. 2A, 2B and 2C. Another part of laser beam 412 is blocked by laser-blocking portion 432 so that to prevent the target region 230a from being irradiated by laser beam 412.

In another embodiment as shown in Fig. 4C, mask 430 has a laser-

blocking portion 432 for blocking part of laser beam 412 from passing through, a first laser-passing portion 434 and a second laser-passing portion 436 each adjacent to one side of laser-blocking portion 432 for allowing another part of laser beam 412 to pass through. In this embodiment, laser beam 412 is separated into two laser beams 210 and 310 to irradiate material source 220. in the meantime, laser beams 210 and 310 also remove the part of layer of material under the exposure of the two laser beams from the border regions 230b and 230c, as illustrated in conjunction with Figs. 3A, 3B and 3C.

X-Y stage 490 is provided for holding material source 220 and working substrate 230. X-Y stage 490 is capable of carrying material source 220 and working substrate 230 to move relative to laser beam 210 and/or 310 along a predetermined path within the X-Y plane, which can be either a straight line or a curved trace. In the embodiment shown in Fig. 4B, an edge 433 between first portion 432 and second portion 434 of mask 430 extends along a first direction 401, and X-Y stage carries material source 220 and working substrate 230 to move relative to laser beam 210 and/or 310 along a second direction 501 (Fig. 5A) which is parallel to the first direction 401.

Under this arrangement and when one laser beam 210 is used as illustrated in conjunction with Figs. 2A, 2B and 2C, a layer of material can be formed onto working substrate 230 with an edge 502, as shown in Fig. 5A. Compared to convention methods, a layer of material formed according to the present invention illustrated above has a clear and sharp edge. In another embodiment, when two laser beams 210 and 310 are irradiated, as illustrated above shown in Figs. 3A, 3B and 3C, laser beams 210 and 310 scan through working substrate 230 to form a layer of material onto working substrate 230 with clear and sharp edges 504, 506, and with a controlled dimension or width 505 determined by edges 504 and 506, as shown in Fig. 5B.

According to a further embodiment, X-Y stage 490 may be controlled to move material source 220 and working substrate 230 along a curved trace 511.

When X-Y stage 490 rotates, mask 430 is controlled to rotate corresponding to the rotation of X-Y stage. As a result, when one laser beam 210 is employed, a layer of material is formed onto working substrate 230 with a clear and sharp curved edge 512, as shown in Fig. 5C. In another embodiment, when two laser beams 210 and 310 are employed, a layer of material is formed onto working substrate 230 with clear and sharp curved edges 514 and 516, and a controlled dimension or width 515 determined by edges 514 and 516, as shown in Fig. 5D.

Fig. 6 is a diagram showing an apparatus 600 for forming a layer of material onto a working substrate according to another embodiment of the present invention. Apparatus 600 has a laser source 610 for generating a laser beam 612. Apparatus 600 further comprises an optical system having a beam attenuator 620, a mask 630 and a mirror 650. Beam attenuator 620 is disposed adjacent to laser source 610 to control the fluence of laser beam 612. Mask 630 is provided next to attenuator 620 to control the profile of laser beam 612. Apparatus 600 differs from apparatus 400 shown in Fig. 4A in that, material source is provided in the form of a foil 222a coated onto a flexible substrate 220a. A galvanometer 680 is provided to control and scan laser beam 612 through working substrate 230, hence to form a path and/or trace onto working substrate 230. The flexible substrate 220a is rolled and loaded onto a rotating feed system 690, which is controlled by a controller 670. In the material layer deposition process, material source 220a may remain stationary or movable relative to working substrate 230 to supply material for the deposition.

Fig. 7 is a diagram showing an apparatus 700 for forming a layer of material onto a working substrate according to a further embodiment of the present invention. Apparatus 700 differs from apparatus 400 shown in Fig. 4A in that, a zero order $\lambda/2$ wave plate 730 is provided adjacent to attenuator 720 and shutter 740 to intersect the linearly polarized laser beam 712 generated by laser source 710. Wave plate 730 rotates the polarization of laser beam 712

such that the laser beam 712 is split by a polarizing cubic beamsplitter 742 to generate an S-polarized beam 712a and a P-polarized beam 712b of equal fluence.

5 Beams 712a and 712b are directed onto material source 220 through working substrate 230, by respective optical elements, namely mirrors 750a, 750b, and objective lenses 760a and 760b. Beams 712a and 712b therefore irradiate material source 220 through working substrate 230 in a tilted manner, forming a gap 236 on working substrate 230. The position and dimension of
10 the gap 236 can be controlled by adjusting the positions of beams 712a and 712b, to match to and cover the target region onto which the layer of material is to be deposited.

By virtue of this arrangement, the target region is prevented from being
15 exposed under the beams 712a and 712b, and border regions at the bottom surface of working substrate 230 adjacent to the target region are overlapped by the beams 712a and 712b. Beams 712a and 712b then irradiate material source 220 to generate induced material to deposit onto working substrate 230. In the meantime, beams 712a and 712b ablate and remove the material
20 deposited onto the border regions to form a trace or path of the layer of material on the target regions with clear and sharp edge(s).

One advantage of an apparatus of this embodiment is that, it allows greater control flexibility in optimizing the laser-ablated deposition with
25 controlled dimension and profile. For example, by adjusting the positions of beams 712a and 712b, the width of the gap 236 formed on working substrate can be varied to form a layer of material onto the working substrate with different width.

30 It should be appreciated that although embodiments of the present invention have been illustrated in conjunction with the accompanying drawings and described in the foregoing detailed description, the invention is not limited

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to the embodiments disclosed, and is capable of numerous rearrangements, modifications, alternatives and substitutions without departing from the spirit of the invention as set forth and recited by the following claims.

CLAIMS

1. A method for forming a layer of material onto a substrate at a target region, comprising:

5 directing a laser beam onto a material source through the substrate
 to generate an induced material from the material source,
 wherein the induced material deposits onto the substrate to form the
 layer of material, and
 wherein the laser beam is to remove the layer of material formed on
10 a border region outside the target region.

2. The method as recited in claim 1, wherein the laser beam passes
through the substrate at an intersecting region overlapping the border
region such that the laser beam irradiates the border region to remove
15 the layer of material formed thereon.

3. The method as recited in claim 2, further comprising blocking a first
portion of the laser beam from irradiating the target region, and allowing
a second portion of the laser beam to pass through the substrate at the
20 intersecting region.

4. The method as recited in claim 3, wherein the border region extends
beyond opposite edges of the target region to form two border zones,
and the method further comprises providing a mask for separating the
25 laser beam into two parts each of which ablates one of the border zones
 to remove the layer of material formed on the border zones.

5. The method as recited in claim 4, wherein the target region is an
elongated area extending along a first direction and greater than a
30 diameter of the laser beam, and wherein the method further comprises
 effecting relative movement between the laser beam and the substrate
 along a second direction parallel to the first direction to form a path of

the layer of material on the elongated area.

- 5 6. The method as recited in claim 5, wherein the substrate moves relative to the laser beam along a curved path, and the method further comprises varying an orientation of the mask to follow the movement of the substrate to form a curve of the layer of material on the substrate.
- 10 7. The method as recited in claim 1, wherein the laser beam is a first laser beam and the method further comprises directing a second laser beam onto the material source through the substrate, wherein each of the two laser beams ablates one border region adjacent to respective opposite edge of the target region to remove the layer of material formed thereon.
- 15 8. The method as recited in claim 7, wherein the first and the second laser beams are split from a single laser source and the first and the second laser beams have equal fluence.
- 20 9. The method as recited in claim 8, wherein the two laser beams pass through the substrate to form a gap therebetween, and wherein the gap overlaps the target region to prevent the target region from being exposed to the first and second laser beams.
- 25 10. The method as recited in claim 9, further comprising adjusting a position of at least one of the first and second beams to vary the width of the gap.
- 30 11. The method as recited in claim 1, wherein the laser beam is a pulsed laser having one pulse peak irradiating the material source to generate the induced material, and another pulse peak ablating the border region to remove the layer of material deposited on the border region.
12. The method as recited in claim 1, wherein the laser beam generates the

induced material and removes the layer of material deposited outside the target region at the same time.

13. An apparatus for forming a layer of material onto a substrate at a target region, comprising:

a laser source for generating a laser beam, wherein the laser beam is to generate an induced material from a material source, wherein the induced material is to deposit onto the substrate to form the layer of material, and

an optical system for directing the laser beam onto a material source through the substrate,

wherein the laser beam is to remove the layer of material formed on a border region outside the target region.

14. The apparatus as recited in claim 13, wherein the optical system is to direct the laser beam to pass through the substrate at an intersecting region overlapping the border region such that the laser beam irradiates the border region to remove the layer of material formed thereon.

15. The apparatus as recited in claim 14, wherein the optical system further comprises a mask having a laser-blocking portion for blocking the a first portion of the laser beam from irradiating the target region, and a laser-passing portion for allowing a second portion of the laser beam to pass through the substrate at the intersecting region.

16. The apparatus as recited in claim 15, further comprising a holder for supporting the substrate, wherein the holder is movable relative to the laser beam, and wherein the mask is movable relative to the laser beam corresponding to the movement of the holder.

17. The apparatus as recited in claim 15, wherein the optical system further comprises a galvanometer for directing the laser beam onto the

substrate, wherein the galvanometer is to direct the laser beam to move relative to the substrate, and wherein the mask is movable relative to the substrate corresponding to the movement of the laser beam.

5 18. The apparatus as recited in claim 15, wherein laser-passing portion has two openings each adjacent to one side of the laser-blocking portion for separating the laser beam into two parts to pass through a respective interacting portion adjacent to target region.

10 19. The apparatus as recited in claim 13, wherein the optical system further comprises a beam splitter for spitting the laser beam into two split laser beams, wherein the two split laser beams are directed through the substrate to define a gap therebetween.

15 20. The apparatus as recited in claim 19, wherein the gap covers the target region.

20 21. The apparatus as recited in claim 20, wherein the optical system is to adjust a position of at least one of the two split laser beams to vary a width of the gap.

22. The apparatus as recited in claim 21, wherein the beam splitter is a polarizing cubic beam splitter for generating a P-polarized beam and an S-polarized beam with equal fluence.