Excimer laser patterning of thick and thin films for high density packaging

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ABSTRACT

Excimer laser projection methods have been developed to directly create high resolution electrical circuits in both thin and thick-film metallic layers in order to form robust, compact Multi-chip Module interconnection devices (MCM's), miniature sensor elements, miniature flexible printed circuits (FPC's), antennas etc at high speed and low cost.

Patterning over small or large areas is possible at high speed using simple step and repeat or more complex synchronous mask and workpiece scanning methods. Ablation rates depend strongly upon the thickness of the metal layer varying from complete metal removal with 1 laser shot for thin films (eg 100nm thick) to multiple 10s of shots for films up to 30μm thick. Pulsed energy densities vary in the range < 1J/cm2 for sub 0.1μm evaporated films to a few J/cm2 for screen printed polymer thick films or thick sputtered films.

Multiple layer interconnect circuits and complex advanced sensor devices have been successfully fabricated using these excimer laser metal film patterning methods together with laser via drilling and patterning of dielectric layers using a laser tool with appropriate level to level alignment and mask changing and scanning facilities.

Keywords: Laser patterning, thick film, thin film, mask projection.

1. INTRODUCTION

There is an increasing requirement to prototype and manufacture complex sensor devices and electrical interconnect circuits at metal track densities much higher than can be achieved with acceptable yield by conventional screen printing, etching or phototool processing. More and more lasers are being used to overcome the limitations of these processes. Direct laser raster exposure of resists is already used to replace conventional contact phototool processing in advanced printed circuit board (PCB) processing. Several high speed exposure tools are already available commercially. Pulsed Nd:YAG laser vector writing tools are also available for PCB prototyping at high track densities using direct resist ablation and laminate metal cutting [1]. PCB drilling tools using high speed scan optics and high repetition rate pulsed Nd:YAG lasers for vector processing and drilling of vias are also well developed [2].

Such vector processing of track patterns in laminate metal layers may be appropriate for prototyping PCB circuitry but is too slow for mass production. Direct pulsed-laser writing methods can also be used to selectively pattern the thick and thin film layers used in complex multi-chip modules (MCM's), flexible PCB's (FPC's) and other high-density interconnection circuitry. Again such methods are appropriate for prototyping circuits but unsuitable for low-cost high-speed mass production. Hence there exists the need to be able to selectively pattern thick and thin film layers at high resolution over modest areas (eg 50x5Omm) at high speed with high yield and at low cost.

All these requirements can be met using UV excimer laser mask projection techniques to transfer the whole circuit pattern from a mask to the substrate in one process. Excimer laser mask projection processes can be used to pattern all the layers in electronic interconnect, sensor and display devices in materials such as screen printed polymer thick films (PTF), screen printed carbon, silver or gold inks, sputtered, evaporated or electro-deposited metal films, spun-on or laminated dielectric layers, transparent conductive oxide (TCO) layers or active layers such as amorphous silicon (α-Si). This paper describes the UV excimer laser ablation properties of various films and identifies the optimum process parameters. The optical techniques and hardware required to pattern at high resolution are described and examples of multi-level devices made using such techniques are given.

2. THICK AND THIN FILM ABLATION

Figure 1 is a schematic diagram showing how the beam from a pulsed UV excimer laser interacts with a polymer thick film or thick sputtered or deposited metal layer. In this case each pulse removes a fraction of the film thickness and hence several pulses are needed for complete film removal to the substrate. Because of the short laser pulse duration and high absorption coefficient the area of metal film adjacent to the exposed region is undamaged and high resolution structures with track widths down to a few gm can be formed. Ablation rate depends on the optical absorption coefficient of the film(i.e. film material and composition) and the laser wavelength used. Figure 2a shows ablation rates for 20µm thick screen printed tungsten inks against laser fluence at 248nm. Figure 2b shows equivalent data in terms of number of pulses needed to completely remove a 2um thick electrodeposited gold layer from a fired alumina substrate.

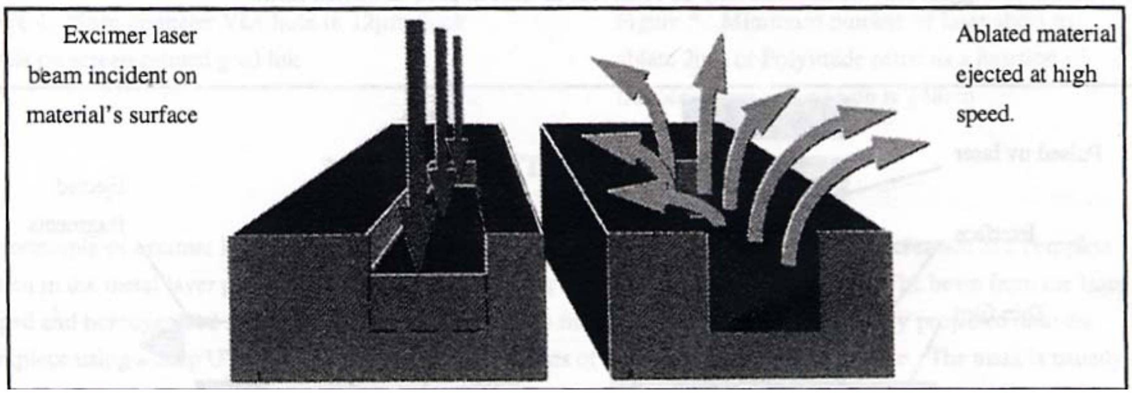

Figure 1. Excimer Laser interaction with polymer thick films

In general for high quality film removal, with all metal removed between tracks, it is necessary to operate at fluences in the range 2 to 3J/cm2 giving removal rates of between 0.5 and 5µm/shot. Transparent Conductive Oxide (eg Indium Tin Oxide or SnO2) films on glass substrates have similar ablation properties with several laser shots needed at a fluence of about 1J/cm2 to completely remove an 80Ω film.

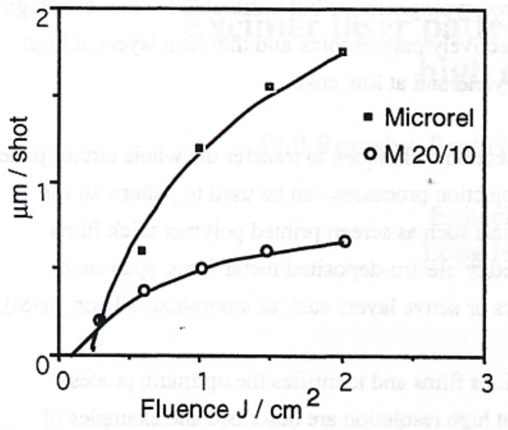

Figure 2a Etch rate against fluence for 2 types

of screen printed tungsten paste.

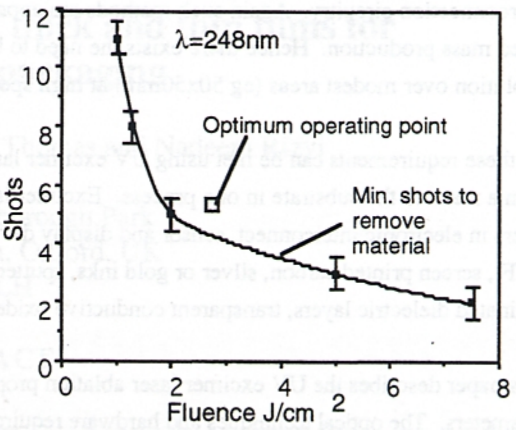

Figure 2b Min. number of laser shots to remove

2µm thick electrodeposited gold
from a ceramic substrate as a
function of fluence.

Metal films with thickness less than about 100nm can be patterned by a single shot process as shown schematically in fig. 3. In this case the incident laser pulse is only partially absorbed by the film so that a small part of the energy reaches the film / substrate interface. The discontinuity at the interface produces high electric field gradients which cause the thin film to be ejected from the surface at high speed. The thinner the film the lower the ablation threshold. For 100nm aluminium film sputtered onto polymer substrates fluences of up to 1J/cm2 are needed for clean film removal. For 10nm NiCr film on glass the threshold fluence is only 50mJ/cm2. It is important to note that since the metal film is shocked from the surface and not directly cut, the edge quality of the patterned area is dependent upon the quality of the deposited layer - the finer the grain structure of the deposited film the better the quality of the edge. For some metals then is evidence to suggest that the material may be removed, at least in part, in molten form.

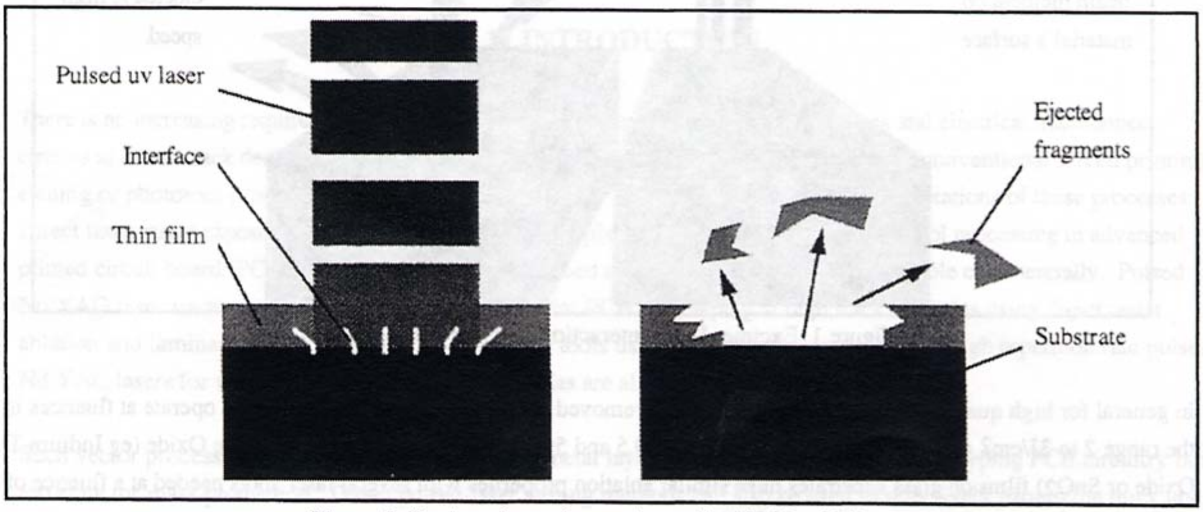

Figure 3. Excimer Laser Interaction with thin Metal Films

Thick dielectric layers can have significantly higher ablation rates and lower ablation threshold fluences compared to thick metal films. For optimum quality and resolution the absorption coefficient of the laser radiation in the dielectric should be in the range 1 - 5x10^{4}cm^{-1}. A high absorption coefficient means low ablation threshold fluence and hence such polymers layers can be processed on delicate substrates without damage to underlying structures. Figure 4 shows an example of a tapered via hole drilled through a 12µm thick dielectric layer at a fluence of 0.3J/cm2 using 248nm without damage to the delicate screen printed gold pad below.

Figure 5 shows the number of shots needed to remove a 2µ thick polyimide (PI) resist layer on top of an evaporated 100nm thick gold layer on a glass substrate. At a fluence of 100mJ/cm2 the PI is removed cleanly without damage to the lower gold layer.

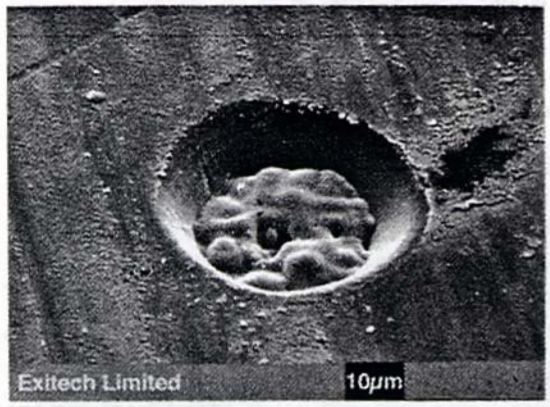

Figure 4. 35µm diameter VIA hole in 12µm thick

BCB on screen printed gold ink.

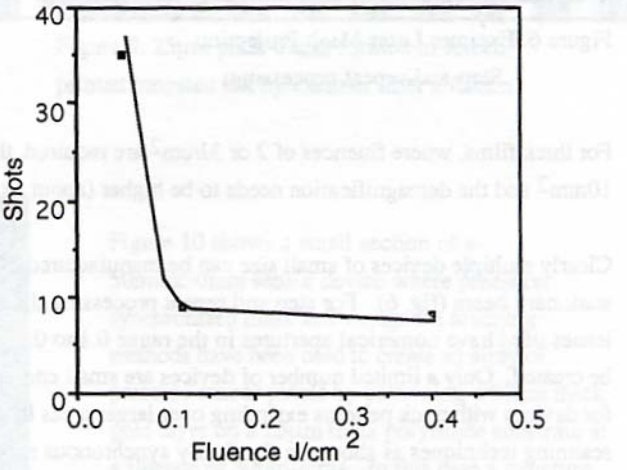

Figure 5. Minimum number of laser shots to

ablate 2µm of Polyimide resist as a function of fluence. Laser wavelength is 248nm

3. LASER PATTERNING METHODS

The principle of excimer laser mask projection is shown in figure 6. This method allows the creation of a complete pattern in the metal layer providing a means for fabricating complex circuits at high speed. The beam from the laser is shaped and homogenized to illuminate the full pattern on a mask. This pattern is subsequently projected onto the workpiece using a deep UV (DUV) reduction projection lens of appropriate numerical aperture. The mask is usually of a standard chrome-on-quartz type as used routinely in the semiconductor industry. Such masks can be operated safely at pulse energy densities up to 100mJ/cm2 and powers up to 20 watts/cm2 if the chrome is of a suitable type. The area that can be exposed at the substrate is limited by the maximum pulse energy available from the laser and the energy density needed to effectively ablate the material. For thin films with threshold fluences of a few 100mJ/cm2 illumination areas of up to a few cm2 are possible. In such cases a lens demagnification factor of as low as 2x is appropriate.

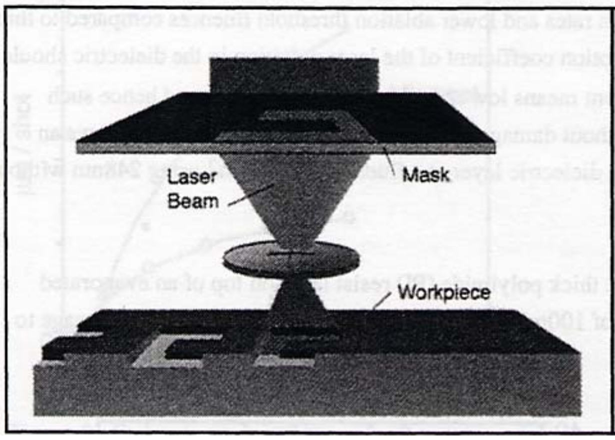

Figure 6. Excimer Laser Mask Projection.

Step-and-repeat processing

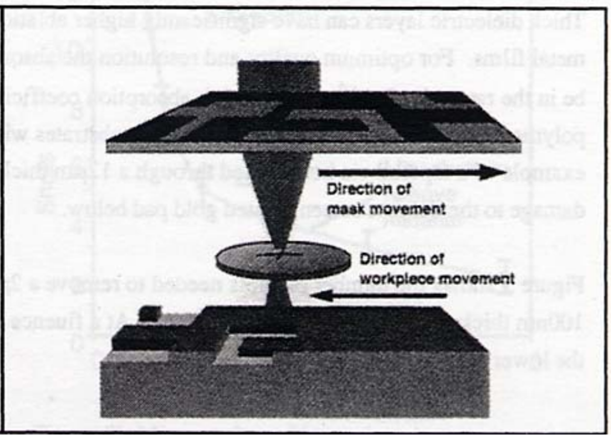

Figure 7. Excimer Laser Mask Projection.

Synchronized mask and workpiece scanning.

For thick films, where fluences of 2 or 3J/cm2 are required, the area that can be exposed at the workpiece is only about 10mm2 and the demagnification needs to be higher (about 5x) to retain a safe fluence at the mask.

Clearly multiple devices of small size can be manufactured by step and repeat movement of the workpiece under the stationary beam (fig. 6). For step and repeat processing the structure scale size is set by the lens resolution. Typical lenses used have numerical apertures in the range 0.1 to 0.2 enabling structures with track widths down to a few um to be created. Only a limited number of devices are small enough to be manufactured in step and repeat mode however, so for devices with track patterns extending over larger areas it is necessary to use synchronized mask and workpiece scanning techniques as shown in fig. 7. By synchronous movement of the workpiece and mask in opposing directions at relative velocities and distances set by the lens magnification it is possible to write unique patterns over areas of the substrate set only by the limitations on the mask size. The accuracy of pattern formation is now set not only by the optical resolution of the lens but more importantly by the accuracy and repeatability of the mask and workpiece stages and the precision of the CNC control system in co-ordinating this motion.

In practice 1 to 2µm precision can be readily achieved over typical device sizes up to 50x50mm by use of servo controlled precision stages with linear encoders in a temperature controlled environment.

Since at present the maximum readily obtainable mask size is 7”x7”, the practical maximum device size achievable is set by the lens demagnification required. This translates to devices of about 75mm x 75mm for a thin film device, and 37mm x 37mm for a thick film device.

Figure 8 shows an example of a section of a test track pattern formed by structuring a 20µm thick layer of screen printed tungsten ink on a green ceramic substrate at 2J/cm2 using 248nm laser light. The track width and pitch are 50µm and 100µm respectively and the total structure size is 6mm x 25mm. Track widths and pitches as small as 12.5µm and 25µ respectively have been produced in tungsten ink by this method as shown in fig. 9.

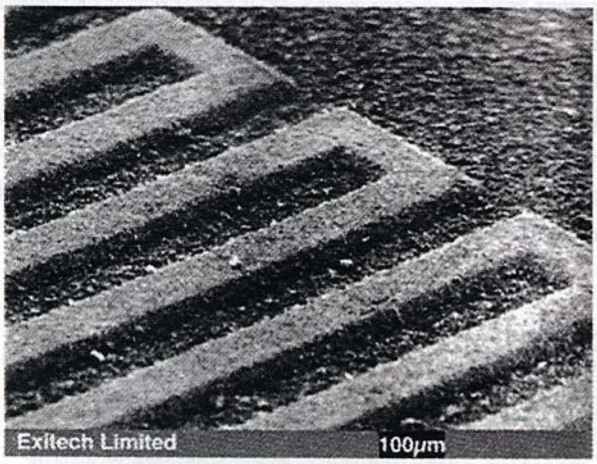

Figure 8. Test track raster pattern formed in 20μm

thick tungsten ink on green ceramic substrate by ablation. mask and workpiece scanning. Track pitch is 10um

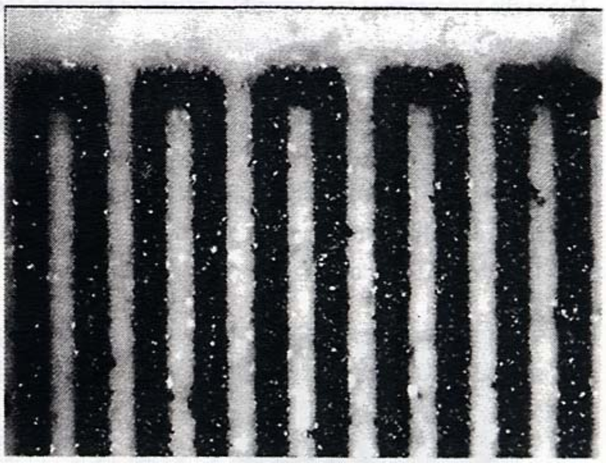

Figure 9. 25μm pitch tracks formed in screen

printed tungsten ink by excimer laser

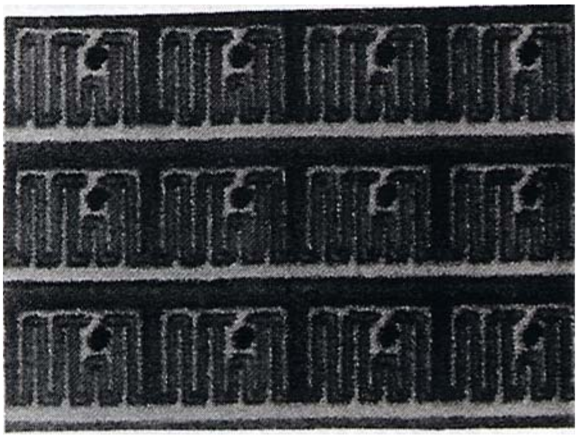

Figure 10. Section of a pixilated pressure sensor device created by selective removal of 50nm thick gold film on polyimide. Pixel size is 100 x 100μm

Figure 10 shows a small section of a 50mmx50mm sensor device where precision synchronized mask and workpiece scanning methods have been used to create an array of pressure sensor pixels by patterning a 50nm thick gold layer on a 25μm thick polyimide substrate at a fluence of 300mJ/cm2. In this case a structure pitch of 10um has been realized. The black dot in the centre of each patterned pixel is a via drilled through the 25μm PI structure by similar excimer laser mask projection techniques.

4. PROCESS RATES AND COSTS

For track formation by serial scribing the process time depends critically upon the length and complexity of the pattern. For mask projection however the complexity or detail of the pattern is not important and the total process time is only a function of the total area to be patterned and the energy dose required per cm2 to remove the film. For thick films the ablation requirement is approximately 15 shots of 2J/cm^2 giving a total dose of 30J/cm^2. For thin films the dose required is over an order of magnitude less (e.g. 1J/cm^2 and 1 shot).

Hence the process time can be readily estimated knowing the pattern area, the dose required and the laser power delivered to the workpiece. For example an excimer laser rated at 60watts can deliver at least 30watts to the substrate so that films needing a dose of 30J/cm^2 can be patterned at a rate of 1cm^2/sec. Thin films can in principle be patterned at rates up to 10 times higher but in practice lower limits are often set by the maximum speed of the translation stages.

Present excimer lasers tools operating in industrial environments cost about S75/MJ to operate including all parts, gases and services. This level of cost implies that thick film devices can be fabricated at a cost of less than 0.3c/cm2 whereas thin film devices can cost an order of magnitude less.

5. PATTERNING TOOL

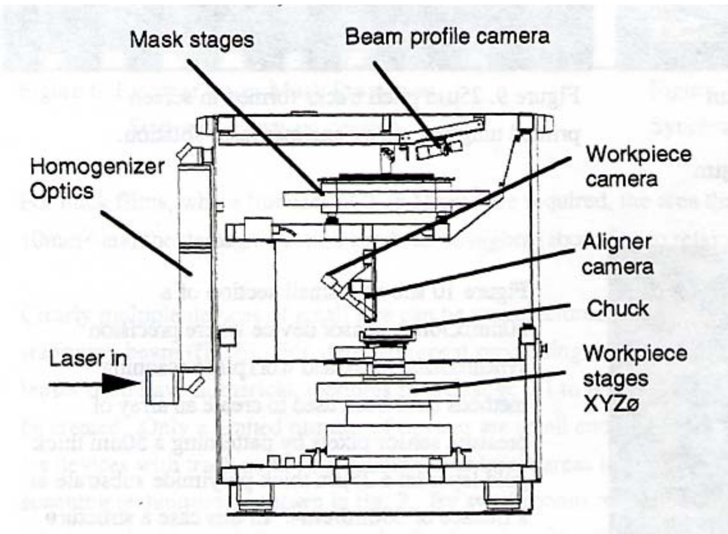

Figure 11. Series 8000 excimer laser mask scanning patterning tool.

Figure 11 shows the elements of the Exitech Series 8000 patterning tool. The laser is mounted behind the tool. The beam delivery system contains appropriate beam shaping and homogenization optics to create a uniform spot at the plane of a mask held on an open-frame CNC controlled X Y stage set. A projection lens of appropriate magnification transfers the pattern of the mask onto the workpiece which is mounted on precision air-bearing X Y stages. An elevator stage with 0.1µm resolution coupled to a diode laser based height sensor system maintain the workpiece at the correct height during processing.

A rotation stage is also incorporated to enable alignment with existing patterns or circuitry on the workpiece using an off-axis viewing camera and vision analysis software. Workpiece viewing optics, beam profile monitoring optics and fume extract and assist gas systems complete the tool.

With such a tool thick and thin-film devices with track pitches down to 10µm and areas up to 50x50mm have been successfully fabricated.

6. DEVICE FABRICATION

The techniques discussed above and the tool described in section 5 have been used to fabricate prototype multilevel MCM's with 50µm wide tracks cut into screen printed tungsten ink. Figures 12a and 12b show 2 of the 8 levels cut by laser patterning. For each level a green ceramic substrate with 4 identical fully coated regions as shown in fig. 12c is loaded onto the chuck and aligned using the screen printed alignment marks on each side of each device. The appropriate mask pattern is selected and the unwanted ink ablated to leave the required structure. The process is repeated 4 times to complete the substrate. This process is repeated for each of the 8 levels with appropriate level masks selected. For the structures shown the vias were made by conventional punching prior to screen printing of the ink but in practice laser drilling of the vias is also possible on the same tool using a high-fluence small-field lens operating in step-and-repeat mode. The 8 levels of the structure are gold plated, assembled and fired to create a compact, robust, low-loss, high-frequency MCM which after addition of surface mount components is used in a medical implant device.

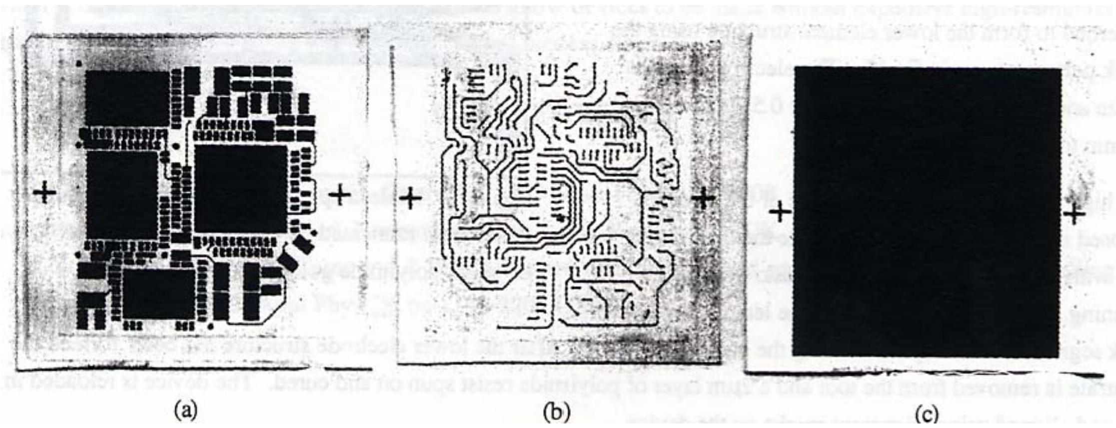

Figure 12. Tungsten ink layers a) Patterned top layer for SMDs, b) Patterned intermediate layer, c) layer before laser patterning.

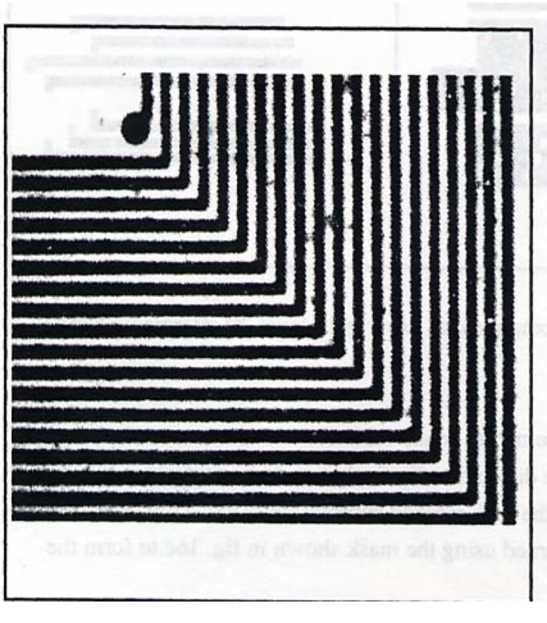

Figure 13. Part of an antenna structure ablated into tungsten ink. Overall size is 6mm x 10mm

Figure 13 shows part of an antenna fabricated from similar metal material by excimer laser mask projection. The tungsten paste depth is 100μm and the pitch of the pattern is 100μm. Manufacture of such a high aspect ratio structure by direct screen printing is not possible.

The manufacture of a single layer high temperature gas sensor element has been demonstrated using the same fabrication methods. The device was made by screen printing a 1mm x 1mm block of platinum ink with contact pads on an aluminium substrate. After firing the ink was patterned to transform the block into an interdigitated line by projecting the complete line pattern in one process step. As the ink was thin (0.5μm) only 3 laser shots with 2J/cm2 were needed to complete the process.

Sensor devices can be fabricated rapidly by patterning evaporated or sputtered metals. Multiple level devices can be built up using excimer patterning of the metal in combination with laser drilling or shaping of a dielectric layer applied by spinning or other means. Figure 14 shows an example of part of a 3-layer dielectrophoretic bioparticle sensor fabricated by this process. Initially 100nm of gold are evaporated onto a glass substrate and patterned to form the lower element structure using the mask pattern shown in- fig 15a. The electrode pitch is 20µm and one laser shot is needed at 0.5J/cm2 and 248nm to produce the full pattern.

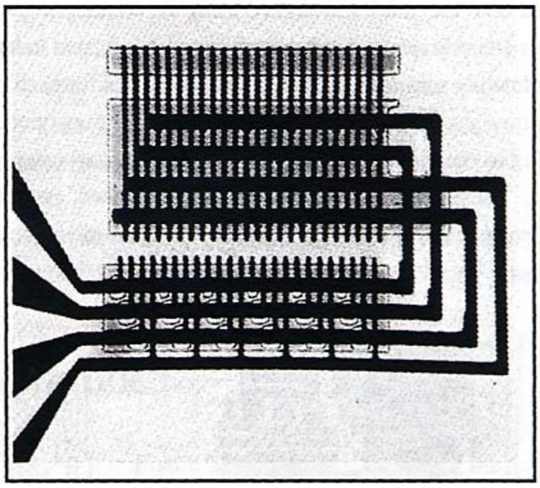

Figure 14. Dielectrophoretic bioparticle manipulator component fabricated by direct laser ablation of 3 layers of gold / polyimide gold.

The high resolution area in the centre of the device is exposed in step and repeat mode while the outer large area with lead-ins is covered using mask/workpiece scanning. This process means that the length of the fine track segment can be adjusted during the laser printing step. After the lower electrode structure has been formed the substrate is removed from the tool and a 2µm layer of polyimide resist spun on and cured. The device is reloaded in the tool and aligned using alignment marks on the device.

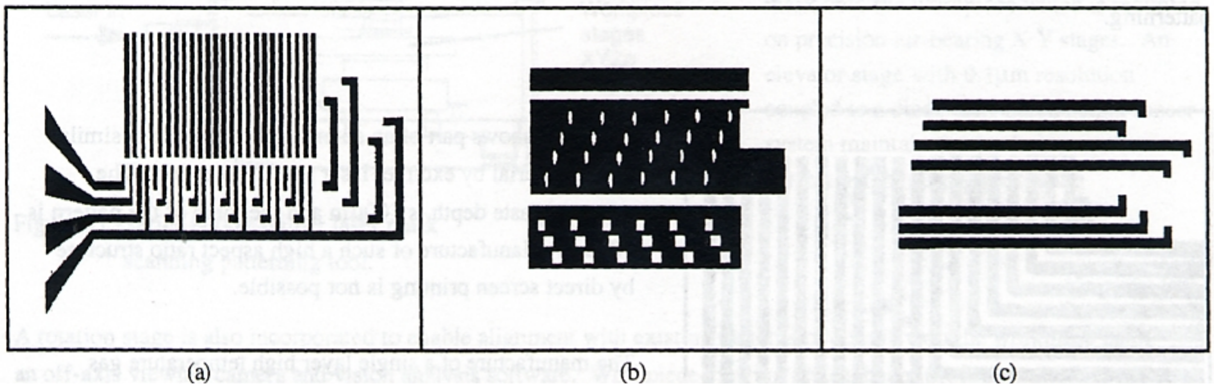

Figure 15. 3 levels of mask used to fabricate a bioparticle sensor component a) lower gold level, b) intermediate resist layer and c) upper gold layer.

A new mask is placed in the beam (fig. 15b) and the polyimide patterned to create via holes and to remove selected areas of the dielectric. A low fluence is used (80mJ/cm2) that ablates the dielectric effectively but does not damage the lower gold layer when exposed. The device is removed once more from the tool, masked appropriately, and a top layer of gold applied. After return to the machine and aligned this layer is patterned using the mask shown in fig. 16c to form the complete 3 level structure.

The device shown in fig. 14 is one subcomponent in a large sensor device used for labelling and detecting organisms in water. Excimer laser mask projection patterning of metal and dielectric films is an effective technology to develop and manufacture such devices rapidly at low cost.

7. CONCLUSION

Excimer laser mask projection is a novel method that can be used for creating high resolution circuitry in thin and thick film metal layers. Miniature circuits and sensor devices with single or multiple layers can be fabricated with high resolution at high speed and at low cost. Such methods allow devices to be made without expensive high-resolution lithography equipment and without wet chemical etching process steps.

8. REFERENCES

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