DIRECT MANUFACTURE OF MINIATURE BIOPARTICLE ELECTRO-MANIPULATORS BY EXCIMER LASER MASK PROJECTION

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ABSTRACT

Excimer laser mask projection techniques have been developed and used in order to directly manufacture miniature thin film devices for the electro manipulation and separation of bioparticles using travelling electric field dielectrophoresis effects.

3 level devices with electrode structures with 10μm pitch have been fabricated by sequential direct laser ablation of thin metal and resist layers using both static and scanning mask projection techniques.

Key: Excimer laser, mask projection, biosensors.

1) INTRODUCTION

Direct laser patterning of thin films allows the possibility of rapid prototyping and low cost manufacture of complex sensor devices, electrical interconnection circuits and miniature . flexible printed circuits with structures and track densities beyond the limits achievable by conventional phototool and etching processes.

The slow manufacturing rate of direct vector writing of such structures can be overcome by the use of excimer laser projection techniques, where complete device structures are created repetitively by the transfer of a complex pattern from mask to device [1].

This paper describes the basic principles of excimer laser thin film ablative patterning by mask transfer methods and describes the equipment used for such activities.

As an example of this type of processing details are given of the methods used to prototype a miniature Travelling Wave Dielectrophoresis (TWD) Conveyor track thin film device. This structure forms a key part of a more complex 'biofactory on a chip' device which is capable of performing a wide range of complex diagnostic tasks in a single, robust, integrated, miniaturised low cost package. Such 'biofactory' devices permit the fully automated and rapid on line analysis of small volume samples and hence are important in the areas of medical and single cell diagnostics, chemical detection and water quality control [2].

2) EXCIMER LASER THIN FILM PATTERNING

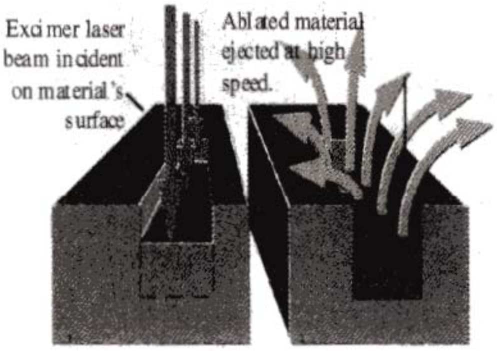

Figure 1 (a)

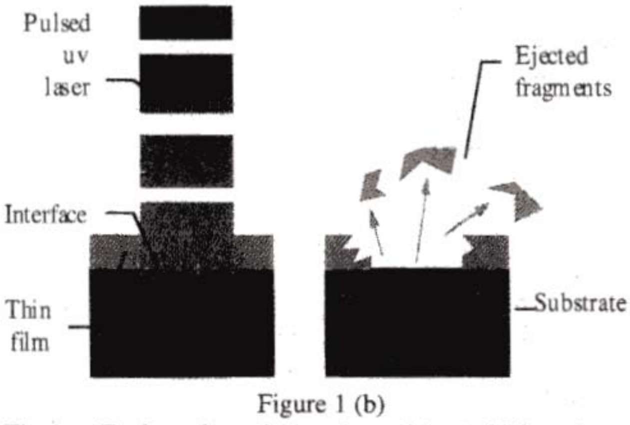

Figure 1 (b)

Fig 1: Excimer laser interaction with a) thick polymer film and b) thin metal film.

Figs 1a and b illustrate the principles of direct patterning of thin films by pulsed excimer laser ablation. Fig la shows the situation for a thin polymer film such as a resist. In this case each pulse from the laser removes a small layer of material which is decomposed and ejected. For pulsed energy densities in the range 0.1 to 1 J/cm^2 the depth of material removed per pulse is generally in the range 0.1 to 0.3µm. Hence for a resist film of perhaps 2µm thickness between 5 and 20 shots are needed penetrate. Fig lb shows the situation for a thin (≤100nm) metal film. In this case generally only one laser shot is needed to heat the layer, cause disruption of the bonding at the interface and ejection of hot film fragments at high speed without damage to the substrate. For films of 100nm thickness a pulsed energy density of up to 1J/cm^2 is needed to cleanly remove the film. For films of 10nm or less energy densities of only a few I0mJ/cm^2 are needed.

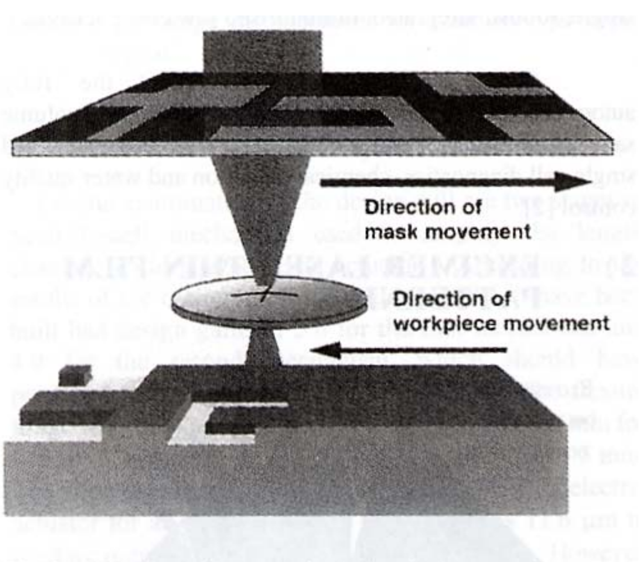

Fig 2: Excimer laser mask projection patterning using synchronised mask and workpiece scanning.

To create a large area complex structure special mask projection methods are used as illustrated in fig 2. The patterns to be created are formed on a chrome on quartz mask plate which is placed in the beam from a pulsed excimer laser which has been suitably shaped and homogenised. A lens images the area of the mask illuminated by the beam to create a reduced pattern on the substrate by direct laser ablation of the thin film. As the laser pulse energy is limited the area exposed at the substrate is generally only a few 10mm^2 (e.g. 4x4mm). To overcome this limitation in order to create unique patterns of larger area the substrate and workpiece are moved in synchronism in both X and Y directions as shown. Such a technique allows direct fabrication of relatively large area (e.g. 50x50mm) thin film devices with high resolution (e.g. 1µm) without the need for complex large field lenses [3].

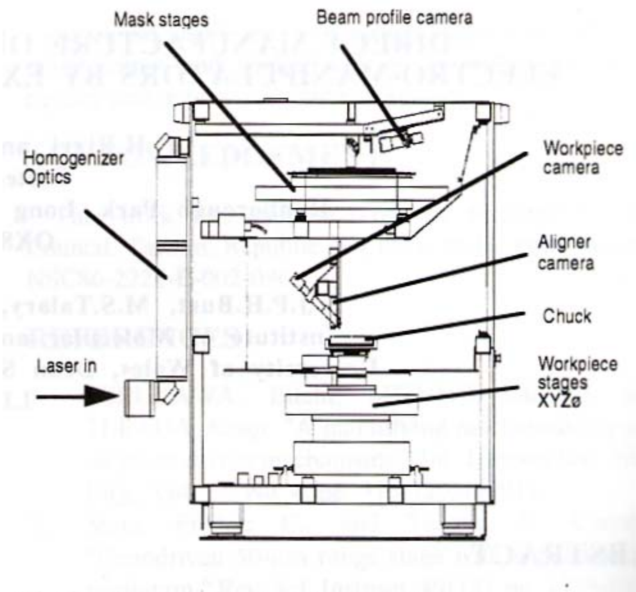

Fig 3: Excimer laser mask scanning film patterning tool.

Fig 3 shows the type of patterning tool used fo such operations. The unit contains high accuracy (± 2µm air bearing X Y stages with 200mm x 200mm travel for substrate motion and 300mm x 300mm travel open frame stages to hold the masks. A projection lens with 10x demagnification, 0.3NA and 1.2 x 1.2mm field allows precision film patterning at the sub micron level while an alternative 4x lens with 0.2NA and 3x3mm field permits faster patterning but at slightly lower resolution (1.5µm). The beam from the laser is shaped and homogenised using various fused silica lenses and lens arrays to create a highly uniform (±5% RMS) pattern of 12x 12mm at the mask surface. A do servomotor controlled attenuator allows accurate control of energy density at the workpiece during processing.

An elevator stage with 100nm resolution and diode laser based height sensor are used to maintain the workpiece at the correct height during processing. A rotation stage at the workpiece is used with an off axis aligner microscope coupled to vision software to permit automatic level to level substrate alignment to be performed.

3) BIOPARTICLE MANIPULATOR MANUFACTURE

Biofactory devices utilize a combination of electrokinetic techniques such a dielectrophoresis (translational motion in non-uniform AC or DC fields) electrorotation (rotation in a rotating AC field) and Travelling Wave Dielectophoresis (TWD) (translational motion in travelling fields) to manipulate bioparticles. Since the exact motion of a particle depends on its particular dielectric properties and that of the suspension medium particles can be selectively separated by utilizing either the inherent differences in their dielectric properties or by the addition of markers such as labelled antibodies to modify their properties.

A complete biosensor consists of many different sub modules with straight and curved conveyors switching junctions, holding sections, rotation chambers, etc so that organisms with different responses can be labelled, separated and identified. The location and identification of organisms is carried out using laser beams, vision systems electrical detectors.

As the device is made from thin metal and polymer layers excimer laser direct patterning is an ideal method for rapid prototyping and low cost production as described above. Since the biofactory is made up of separate modules masks can be made with all the patterns necessary to pattern each module layer. During a laser terming process the mask can be rapidly changed to ‘stitch' together all the patterns required to build up a full device. Such a method allows rapid changes of biofactory layout and functionality.

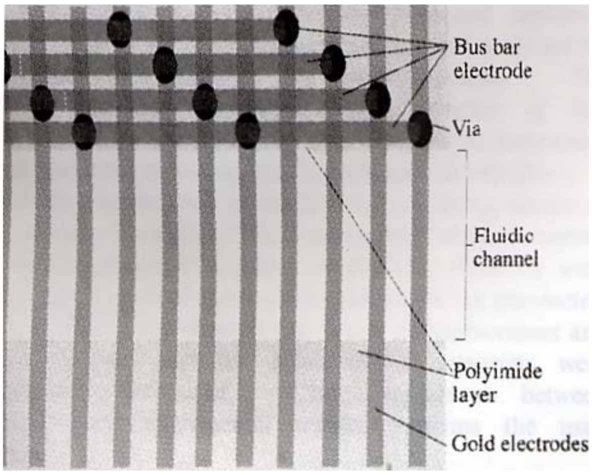

fig 4: Schematic diagram of Travelling Wave Dielectrophoresis conveyor track for the linear movement bioparticles.

Figure 4 shows a schematic diagram of a TWD Conveyor track which is the key module in the biosensor device since it is used to move particles between the other modules. By controlling the magnitude and frequency of the voltages applied to the electrodes which are 90° out of phase the speed and direction of the particles in the channel can be controlled allowing bulk movement of the particles while keeping the suspension medium stationary.

The base electrodes are fabricated on an insulating glass substrate and a polyimide insulator applied over the electrodes to define a channel along the length of the track. Connections are made to the electrodes by the use of via holes through the polyimide allowing 4 bus bars to be applied to make connections to every 4th electrode as shown. This 3 level device has been used to demonstrate the effectiveness of excimer laser direct patterning for the fabrication of such structures. The substrate consists of either a bare glass microscope slide or a slide with a 3μm coating of spun on polyimide. The 10um wide electrodes (vertical lines) are fabricated by laser patterning of a 70-100nm thick evaporated gold film (on 5nm chrome seed layer) using the 4x lens at a fluence of 200mJ/cm^2 in a single laser shot.

Direct patterning of sputtered metal films has been shown to achieve very high resolution (2μm) but evaporated films, although easier to apply. are less reproducible and sometimes have unacceptable edge definition. In this case an alternative technique is used to define the patterns. The evaporated film is overcoated with a 3μm layer of resist which is patterned using 200 pulses at 100mJ/cm^2 to expose the underlying metal. A single pulse at 400mJ/cm^2 is then used to remove the exposed metal. [4]

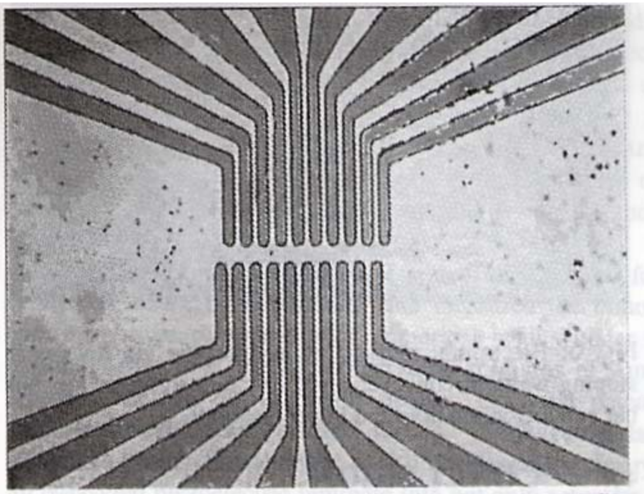

Fig 5: Optical micrograph of laser patterned thin film gold travelling wave dielectrophoresis conveyor track electrode structure: Electrode pitch = 20μm

Finally the residual resist is removed by scanning the complete structure with multiple pulses at 100mJ/cm^2 with an open mask. A fluence of 100mJ/cm^2 is sufficient to ablatively remove the Polyimide cleanly without causing any damage to the metal layer. Fig 5 shows an example of a test TWD conveyor track structure made by this method.

After 1st metal level patterning a 1μm polyimide layer is spun onto the substrate and heat cured. The substrate is replaced in the tool, a new mask indexed and via holes and channels formed in the polyimide by exposure for 60 shots at 100mJ/cm^2. Finally the bus bar connections are formed on top of this polyimide layer by using similar coating and laser patterning methods as for the first layer.

Tests performed on the electrical connection between the top and bottom metal layers showed that poor metal coating on the steep (20°) sides of the via holes led to inadequate reliability to produce satisfactory working electrode arrays having over 1000 through connections. To overcome this limitation the via drilling operation was modified so that holes were 'smeared' in 1 dimension to create an asymmetric via hole with shallow taper angle. Fig 6 shows an example of such a via where the angle has been increased to about 70° by oscillating the workpiece during laser drilling. This picture shows the top bus bar metal track on top of the polyimide insulator.

The underlying conveyor electrode orthogonal to the bus bar is just visible through the via. Such assymetric vias with sloping walls produced through electrical connections with high reliability.

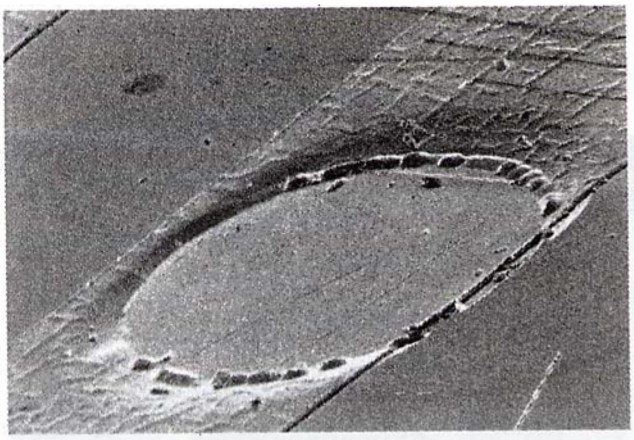

Fig. 6: Electronmicrograph of asymmetric via hole with sloping walls in conveyer track structure showing top bus bar conductor, via hole and lower electrode.

4) CONCLUSION

An excimer laser mask projection tool has been used to successfully pattern directly all 3 layers in a Travelling Wave Dioelectrophoresis conveyor track module to establish the protocols necessary for manufacture of a full biosensor device. Based on these laser techniques a complete biosensor device is being prepared to be used for the active analysis of parasites in potable water.

5) REFERENCES

1. Rumsby P.T, Rizvi N.H, Harvey E.C and Thomas.D. "Excimer laser patterning of thick and thin films for high density packaging in "Micro electronic Packaging and Laser Processing" SPIE Vol 3184 Ref: 3184-24(1997).

2. Talary M.S, Burt.J.P.H, Tame.J.A. and Pethig.R. "Electromanipulators and separation of cells using travelling electrofields' J.Phys D. Appl Phys 29 pp 2198-2203 (1996).

3. Harvey E.C. and Rumsby P.T. 'Fabrication techniques and their application to produce novel micromachined structures and devices using excimer laser projection" in `Micromachinery and microfabrication process technology III' SPIE Vol 3223 Ref: 2332-04 (1997).