

Direct Manufacture of Miniature Bio-Particle Electro-Manipulator Devices using Excimer Laser Mask Projection Techniques*

Nadeem H. RIZVI**, Phil T. RUMSBY**, Malcolm C. GOWER**, Julian P. H. BURT***,
Mark S. TALARY***, John A. TAME*** and Ron PETHIG***

Excimer laser mask projection techniques have been developed and used to manufacture directly miniature thin film devices for the electro-manipulation and separation of bio-particles using travelling-wave dielectrophoresis effects. Multi-level devices with 10 μ m-wide electrode structures have been fabricated by using excimer laser ablation techniques in both static and mask scanning modes of operation. A prototype device produced in this manner has been used to identify viable and non-viable pycysts.

Keywords: excimer lasers, ablation, biofactory, mask projection, dielectrophoresis

1. Introduction

Direct laser patterning of thin films or bulk materials 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 processes.

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

* Received August 12, 1998

** Exitech Limited, Long Hanborough,
Oxford OX8 8LH, UK

*** Institute of Molecular and
Biomolecular Electronics, University
of Wales, Bangor LL57 IUT, Wales

This article details the basic principles of excimer laser ablation using mask transfer methods and describes the equipment used for such activities. One application for this technique is the manufacture of a miniature, thin-film, multi-layer device which uses travelling wave dielectrophoresis (TWD) effects for the manipulation, identification and analysis of bioparticles. Such devices are often called "Biofactory on a Chip" (BFC) systems and are compact, robust, low-cost packages which permit fully automated and rapid in-line analysis of micro-volumes of samples and hence are important in the areas of medical and single-cell diagnostics, chemical detection and production, food purity controls and water contaminant detection (2).

2. Excimer Laser Ablation

Excimer lasers operate in the ultraviolet (UV) region of the spectrum and hence have relatively high photon energies. Laser ablation occurs when the excimer laser interacts with a material and inter- and intra-molecular bonds are broken by the absorption of the UV photons. This leads to

small amounts of material being ejected at high speeds from the exposed area. This is shown schematically in Fig. 1. Typically, single-pulse laser energy densities in the range 0.1 J/cm^2 to 1 J/cm^2 lead to material removal rates of around $0.1\text{-}0.3 \mu\text{m}/\text{shot}$, depending on the material. Hence, for a polymer material such as polyimide, ablation to a depth of $10 \mu\text{m}$ can be achieved in with $\sim 30\text{-}100$ shots.

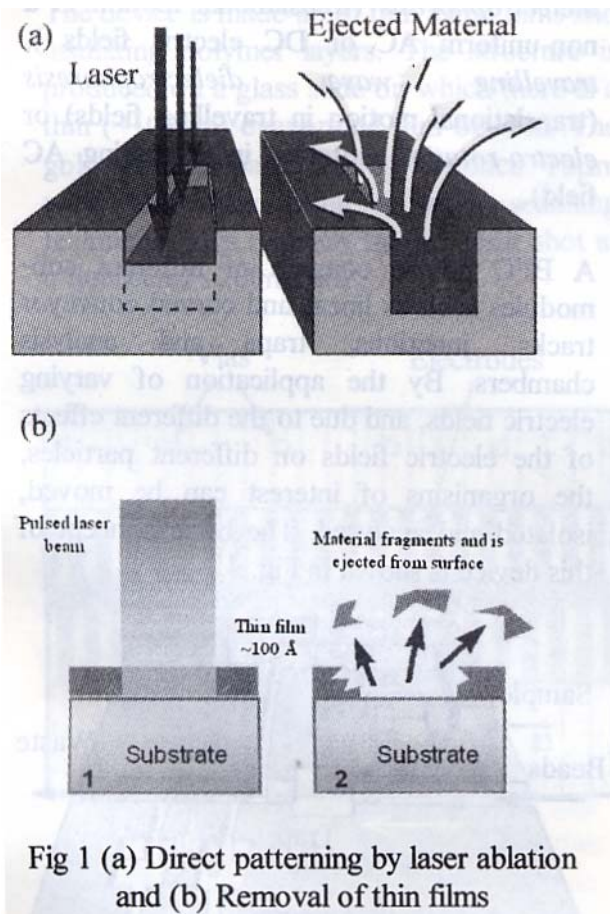


Fig 1 (a) Direct patterning by laser ablation and (b) Removal of thin films

In the case of thin films, generally only a single laser pulse is required to heat the film, cause disruption to the bonding with substrate and ejection of the film fragments away from the substrate without damaging it. If the film thickness is $\sim 10 \text{ nm}$ or less, then a laser energy density of $\sim 10 \text{ mJ/cm}^2$ is generally required but if the thickness is $\sim 100 \text{ nm}$ or so, then higher fluences of $\sim 1 \text{ J/cm}^2$ may be needed for clean film removal.

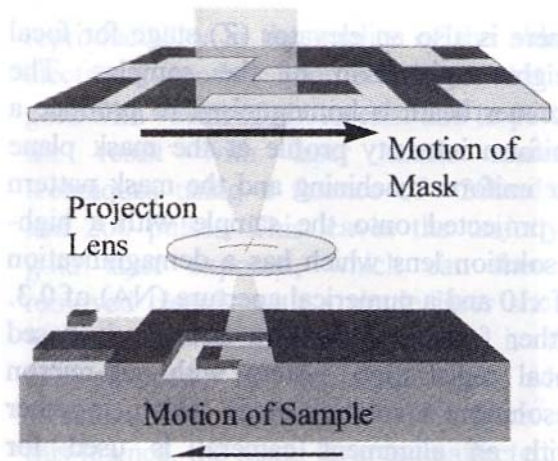


Figure 2. Excimer Laser Mask Projection Patterning using Synchronised Mask and Workpiece Scanning

To produce a large-area complex pattern on a sample, special mask projection methods can be used. The pattern which is required is held on a chrome on quartz plate which is placed in the laser beam. The mask pattern is imaged onto the sample by a high-resolution projection lens. This lens de-magnifies the mask pattern and imprints it into the sample. Due to this demagnification, the size of the image is typically a few square millimetres. Hence, to produce large area patterns, scanning techniques have to be used. In synchronised mask-workpiece scanning, the laser beam stays fixed and the mask and sample are scanned in X and Y across the beam in a raster fashion, as depicted in Fig. 2. This can be achieved with micron accuracy and so large areas (many thousands of square millimetres) can be patterned with high resolution.

An excimer laser patterning tool which incorporates a synchronised mask-workpiece scanning system is shown in Fig. 3.

This Series 8000 micromachining system, shown in Fig. 3, is designed for large-area micro structuring applications. It operates at 248 nm (KrF excimer laser) and contains $400 \text{ mm} \times 400 \text{ mm}$ (X&Y) air-bearing workpiece handling stages and $450 \text{ mm} \times 450 \text{ mm}$ (X&Y) open-frame mask stages.

There is also an elevator (Z) stage for focal height registration of the samples. The excimer beam is homogenised to produce a uniform intensity profile at the mask plane for uniform machining and the mask pattern is projected onto the sample with a high-resolution lens which has a demagnification of x10 and a numerical aperture (NA) of 0.3. Other features include: a laser-diode based focal registration system with sub-micron resolution; a rotation stage which, together with an alignment camera, is used for alignment (i.e. the superposition of different layers in a device); an automated attenuator used to control the laser fluence at the workpiece. All systems are controlled from a central console which also provides full computer control of the stages, laser and diagnostics.

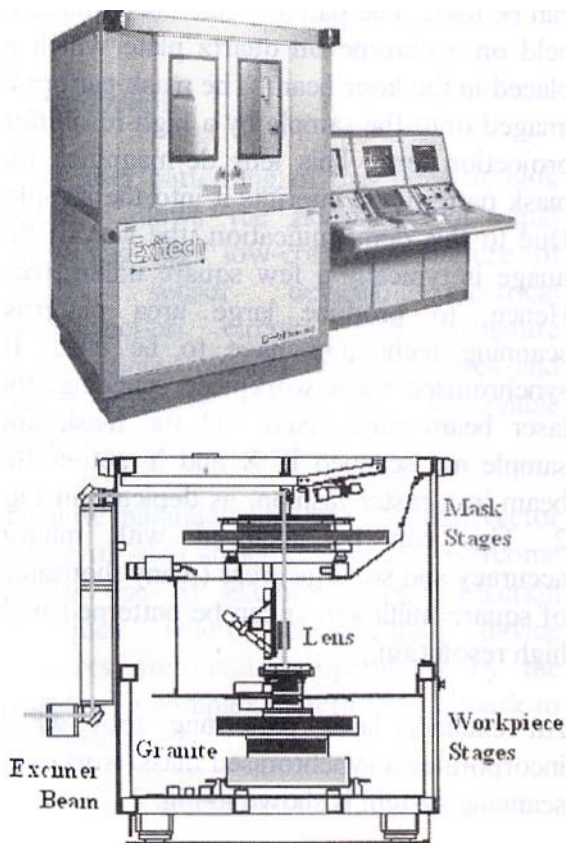


Fig 3 Excimer laser mask scanning patterning tool

The tool described above has been used to manufacture a prototype biosensor device and this is described in the next section.

3. Manufacture of Bioparticle Electro-manipulation Devices

The behavior of bioparticles in electric fields depends on their specific dielectric properties and so by influencing and acting on these differences, the bioparticles can be controlled and analysed. This kind of manipulation can be achieved by electrokinetic effects such as *dielectrophoresis* (translational motion in a non-uniform AC or DC electric fields), *travelling wave dielectrophoresis* (translational motion in travelling fields) or *electro-rotation* (rotation in a rotating AC field).

A BFC device consists of different sub-modules such as linear and curved conveyor tracks, junctions, traps and analysis chambers. By the application of varying electric fields, and due to the different effects of the electric fields on different particles, the organisms of interest can be moved, isolated and analysed. The basic concept of this device is shown in Fig. 4.

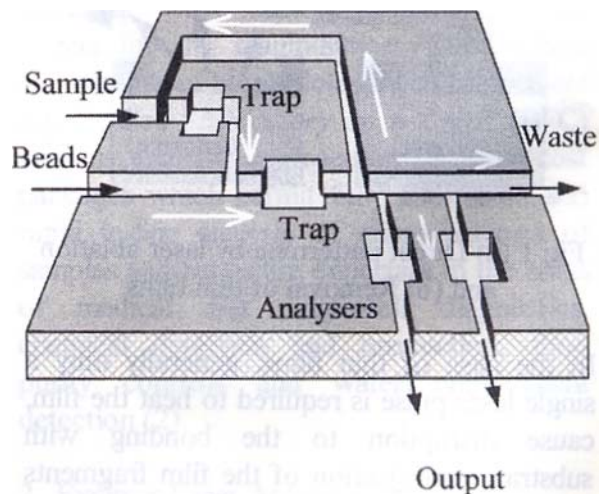


Fig 4 Basic layout of the biofactory device showing linear tracks, traps and analysers.

The sample to be analysed is fed in through micro-channels at the entrance to the device and the organisms can be tagged with polystyrene beads if required. The particles

can then be transported to selective or non-selective traps or moved through to analysis chambers, depending on the electric field which is applied. All the transport of the particles is achieved by the application of the electric fields via miniature electrodes, as shown in figure 5. Identification of the presence of particles can be performed with lasers, optical vision systems or electric detectors.

The device is made up of thin metal films and insulating polymer layers. The structure is produced on a glass slide on which there is a thin (~100nm) evaporated film of gold. The gold is laser-patterned to produce 10µm wide electrodes using a mask scanning technique. This typically takes 1 laser shot at a fluence of ~200mJ/cm².

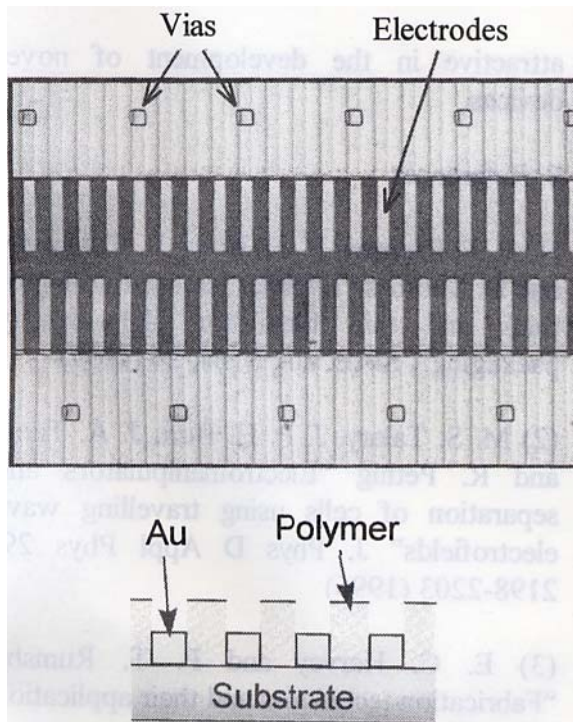


Fig 5 Laser ablated 10µm gold electrodes with via holes laser-drilled through insulating polyimide layer as shown. However, because the quality of evaporated films often leads to a problem of

reproducibility in the quality of the ablated electrode, another approach is to coat the gold with ~3µm of photoresist and to pattern the resist with laser mask scanning techniques using a fluence of ~200mJ/cm² and 200 pulses. This leaves the underlying gold layer exposed, which can then be removed cleanly with a single laser shot at 400mJ/cm². The remaining resist is then laser-stripped by scanning the whole structure with the laser at ~100mJ/cm². At this fluence, the metal layer is unaffected but the resist is ablated away.

Having thus patterned the electrodes into the gold, a layer of polyimide is spun on and via holes are made through the polyimide to the gold below, again by mask projection techniques, with 60 shots at a fluence of 100mJ/cm². The device is removed from the laser tool, gold is coated on top and the device replaced and re-aligned in the machine. Electrical busbars are then laser ablated onto the surface to provide interconnections to the underlying electrodes through the via holes and to make the external connections. Finally, a channel is machined into the polyimide to allow the particles to be electrokinetically manipulated. The device can then be sealed by laminating with an insulator and completed by making the external electrical connections. The basic procedure for the production of this device is shown simply in figure 6.

A section of the 10µm gold electrodes, which were produced by a laser mask scanning technique, is shown in Fig. 5.

4. Results

Having manufactured a prototype bioanalysis device, tests were conducted to detect *Cryptosporidium parvum* oocysts (4).

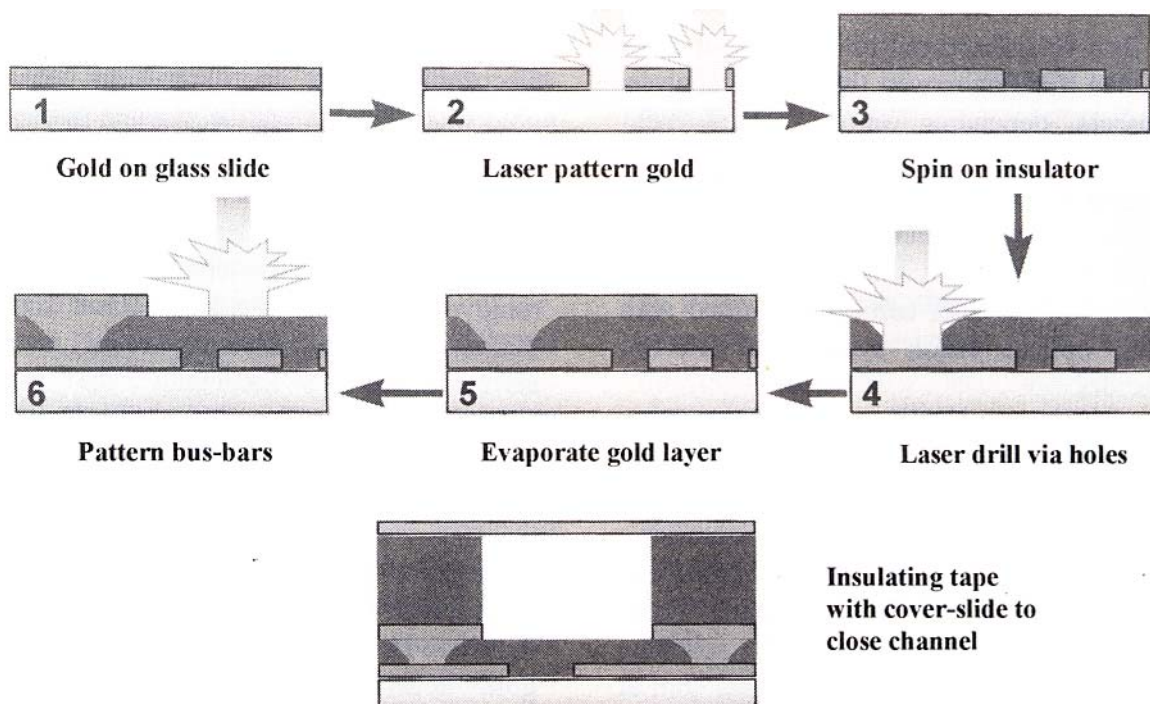


Fig 6 Schematic representation of the process route for the production of a sensor device

A 1.45 μ L volume of water was used which had previously been analysed by other methods to measure its content. The bioanalyser device was used with a 2VAC drive voltage at a frequency of 150Hz for the conveyor tracks and 1.5MHz for the rotation chamber. 55 ± 1 oocysts were trapped representing 90% of the total present in the sample and, in agreement with the initial measurements, 27 of these were analysed to be viable (living) and 24 to be non-viable.

5. Summary

It has been shown that excimer laser machining techniques can be applied to the production of multi-level sensor devices, in this case to the production of a bioanalysis chip. The simple, flexible and quick approach allowed by the laser processing route should enable this type of application to be developed rapidly. Prototyping of different structures and features is ideally performed with laser processing methods and this, allied with the high resolution and accessibility to machine different materials makes the laser ablation process very

attractive in the development of novel devices.

6. References

- (1) P. T. Rumsby, N. H. Rizvi, E. C. Harvey and D. Thomas "Excimer laser patterning of thick and thin films for high density packaging", SPIE Vol. 3184, 24 (1997)
- (2) M. S. Talary, J. P. H. Burt, J. A. Tame and R. Pethig "Electromanipulators and separation of cells using travelling wave electrofields" J. Phys D Appl Phys 29, 2198-2203 (1996)
- (3) E. C. Harvey and P. T. Rumsby "Fabrication techniques and their application to produce novel micromachined structures and devices using excimer laser projection" SPIE Vol. 3223 (1997)
- (4) A. D. Goater, J. P. H. Burt and R. Pethig "A combined travelling wave dielectrophoresis and electrorotation device: applied to the concentration and viability determination of *Cryptosporidium*" J. Phys. D Appl. Phys. 30 L65-L69 (1997)