DEVELOPMENTS IN LASER MICROMACHINING TECHNIQUES

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ABSTRACT

Two techniques are described which further extend the scope of laser micro-processing systems used in industrial applications. One technique – *Synchronised Overlay Scanning* - uses a mask projection concept and is used with excimer lasers to micro-machine multi-dimensional structures into materials. The other technique – *Sync Scan* – is used with galvanometer-based scanner systems and provides an attractive alternative to a mask projection approach in many applications. Both techniques are reviewed in detail and manufacturing applications where they are applicable are introduced.

INTRODUCTION

Laser systems are being employed increasingly in many diverse micro-systems technology (MST) sectors such as biomedicine, automotive manufacture, telecommunications, display devices, printing technologies and semiconductors [1]. These applications areas are using lasers in different ways ranging from basic research and development stages to full production environments. The requirements of the high-specification products which are now being considered are often quite stringent and this has led to many refinements and developments in the lasers systems and laser techniques which are used. These advances, in turn, have promoted the uptake of laser-based technologies by providing technical, manufacturing and economic benefits.

Two laser systems which are at the forefront of industrial integration, and whose applications have reached a high level of production maturity, are excimer lasers and Nd:YAG lasers. These lasers are in use world-wide in many configurations and this paper will address recent advances made with these systems. In particular, the use of excimer lasers to produce 3D microstructures will be detailed and the use of high repetition rate Nd:YAG lasers to pattern large areas rapidly will be described.

MASK PROJECTION TECHNIQUES

The majority of excimer laser systems used in manufacturing applications use the technique of mask projection [2][3]. This method is particularly suited to excimer lasers since their optical properties mean that direct beam focussing is not usually an attractive option and projection methods can be utilised more efficiently in the production of various microstructures. Mask projection methods used with excimer lasers can provide many desirable features [4] but the most important ones which are of interest in MST areas include high feature resolution, fine depth control, excellent reproducibility and the ability to cover large sample areas. Such features, which are depicted in figure 1 for the machining of polyimide, have led to excimer laser systems being used, for example, in the mass production of ink-jet printer nozzles [5].

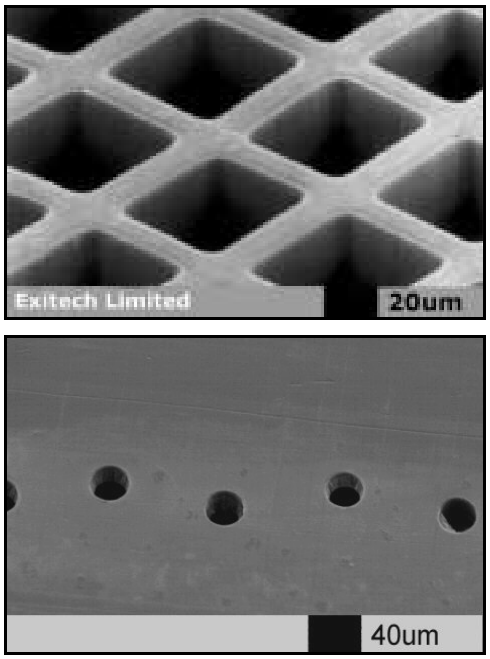

Figure 1. (a) Micro-machining of polyimide and (b) ink-jet printer nozzles, both produced using excimer laser mask projection.

In standard mask projection systems, the depth of the microstructures is controlled by the numbers of laser shots which are fired and the resolution of the features are determined by the mask and the optical projection system. This is demonstrated in figure 2 where microchannels of 18µm depth have been produced in a polymer. The entire sample area (which can be many tens or hundreds of cm^2) is machined under the same laser conditions and so all the microstructures are produced to the same depth. This is, in fact, highly desirable in most applications since uniformity of depth is of particular importance.

In some emerging areas, however, there is a need to tailor the depth profile of the micro-machined structures across the sample area. These applications include micro-fluidic systems, printing devices, bio-medical analytical chips and rapid prototyping technologies – all sectors where multi-functional units are being developed which utilise micro-optical-electro-mechanical systems (MOEMS). The integration of these sub-units having a variety of functions has led to the need for increasingly-elaborate designs for these devices and instigated the development of new micro-machining techniques.

Standard mask projection techniques are very versatile and depth information can be imparted into micro-machined samples by an appropriate synchronisation of the sample position and the laser firing sequence [6]. The level of control of the depth profile required in the above-mentioned applications, however, means that these standard methods are do not extend far enough. To overcome this limitation, a new technique – *synchronised overlay scanning* (SOS) – has been developed.

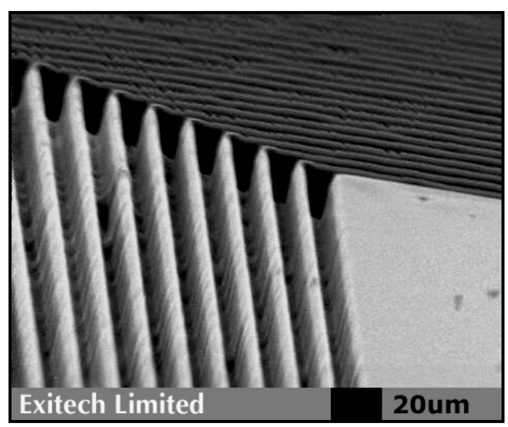

Figure 2. Micro-channels produced by mask projection in polymer showing depth control.

The basics of standard synchronised mask scanning systems have been described in detail previously [7]. To extend this technique and add depth information, the SOS method additionally shapes the laser beam which is used and it is this choice of beam shape which determines the depth profile which is imparted to the micro-structures.

The concept of synchronised overlay scanning is depicted in figure 3.

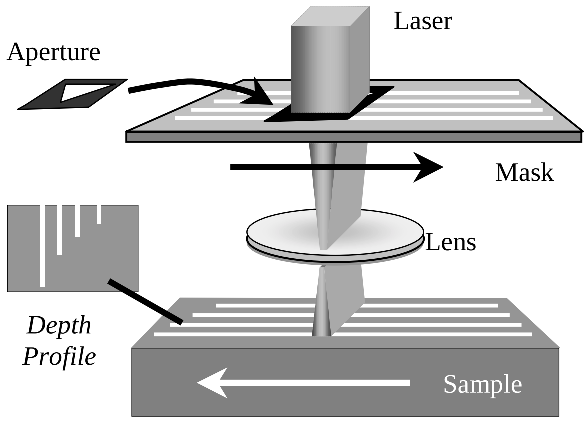

Figure 3. Technique of synchronised overlay scanning.

As is shown above, the SOS technique uses standard synchronised scanning where the mask and the workpiece are moved in unison but in addition to this, an aperture is also placed above the mask to tailor the shape of the beam. The shape of the aperture (i.e. the shape of the beam) determines the depth profile in the sample – hence, as shown in figure 3, a triangular beam shape gives rise to a triangular depth variation in the material as seen in cross-section. Another feature of the SOS method is that the choice of mask (which determines the features to be made) is independent of the choice of beam shape aperture (which controls the depth profiling). This means that there is great scope for selecting appropriate combinations of masks and apertures depending on the specific requirements of the application.

Examples of synchronised overlay scanning are shown in figures 4 and 5 where different combinations of beam shapes and mask have been used. In figure 4, an open rectangle mask was used with a double-triangle aperture as shown. This combination produced the double ramp as shown. In figure 5. The mask was made of open slots which produced channels on the double ramped slope.

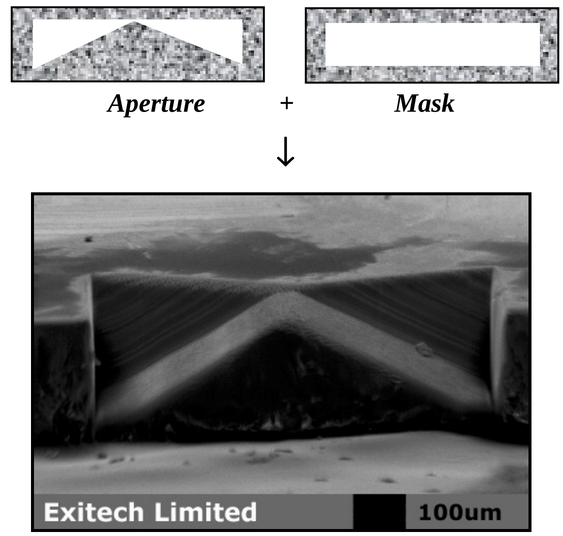

Figure 4. Double ramp produced in PET.

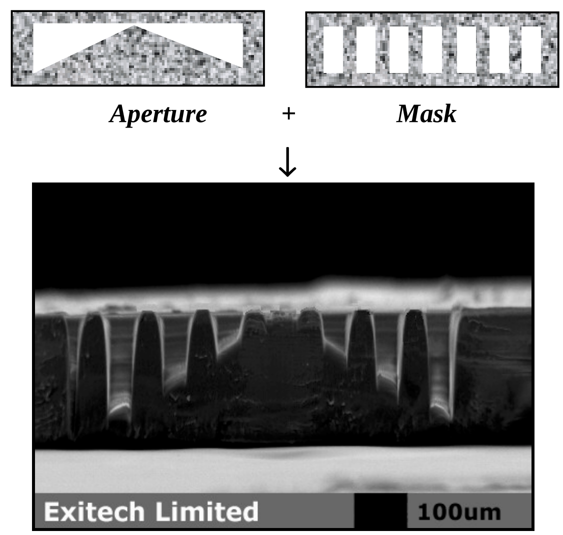

Figure 5. Micro-channels on double ramp in PET.

Figure 6 shows other examples of the results of synchronised overlay scanning where channels and holes have been combined onto depth-varying substrates.

Synchronised overlay scanning techniques are now being applied in many different developmental areas where the combinations of high resolution micro-structures and changes in feature height can be of benefit in the micro-product designs. These applications include:

- Micro-fluidic transport systems and mixing devices where fluids (including inks for printing applications) need to be channeled, mixed and/or transferred through nozzles.
- Innovative designs for lubrication equipment where the lubricant needs to inserted, propelled and extracted from arbitrarily-shaped mechanical parts.
- Components for micro-parts for MST devices, whether produced directly or as a master for further replication.
- Optical devices used for on-chip sensing or for display panel enhancements.

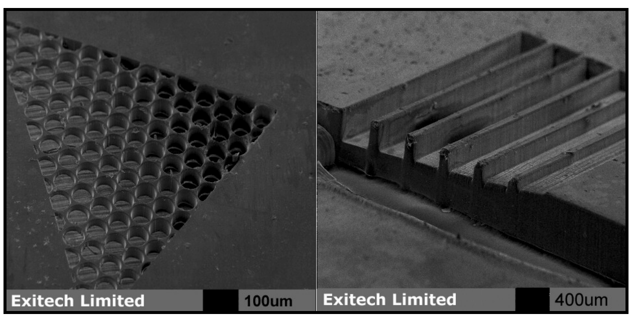

Figure 6. Demonstration of multi-level micro-structuring using synchronised overlay scanning.

DIRECT WRITING TECHNIQUES

The current generation of solid-state lasers (e.g. Nd:YAG, Nd:YVO_3, Ti:sapphire) and some gas lasers (e.g. CO_2 lasers) offer a large number of attractive benefits which include:

- Large wavelength coverage (either directly tunable lasers or frequency-converted models).
- High repetition rates (many tens to hundreds of kilohertz).
- Different pulse durations.
- Wide range of output powers.
- High efficiencies (especially with diode-pumped lasers).
- Relatively small sizes.
- Relatively low running costs.

Mainly due to these reasons, many applications such as via hole drilling, solar panel scribing, display panel production and marking and cutting of devices or products use these lasers. In almost all cases, the technique of direct writing, or serial scribing, is used.

In direct write systems, the laser beam is focussed to a small spot using a lens and either the beam or the sample (or both) are moved around to produce the desired pattern. In some cases, additional galvanometer-controlled scanning mirrors are also included, as shown in figure 7. If scanning mirrors are used, then a flat-field lens is required as this keeps the focal plane position constant irrespective of the angle of the beam being deflected from the scanning mirrors.

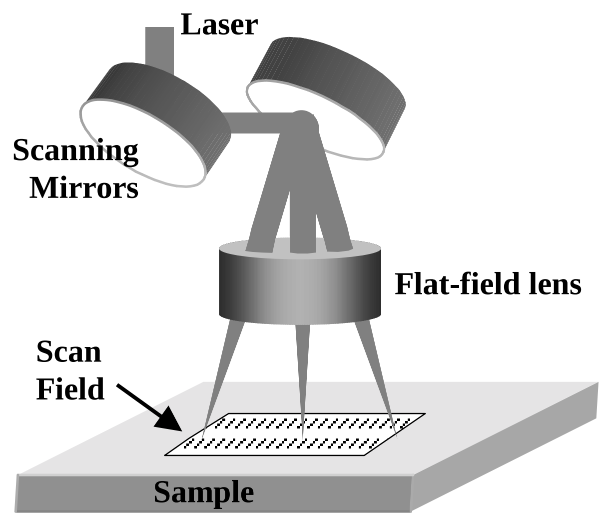

Figure 7. Technique of direct writing.

Beam spot sizes of a few tens of microns can be easily achieved with such systems and the combination of scanner mirrors and high repetition rate lasers means that very high processing speeds can be achieved.

One drawback which has always existed with the type of system shown in figure 7 is that individual scan fields need to be joined (or "stitched") together to form a large area pattern. Hence, the process can be termed step-and-scan since the processing is performed for a scan field, the laser turned off, the sample moved to the position of the next scan field and the patterning re-started. This stepping aspect of this process, when no processing is taking place, obviously causes an increase in the total patterning time. Even though the stepping time delay is only a few hundreds of milliseconds, it can produce significant cumulative effects on total processing times for large samples which in turn can severely impact the economic attractiveness of the whole process.

A solution to this step-and-scan approach is to move the sample continuously while the scanner scans the beam over the area in the scan field. We have extended this approach using sophisticated digital signal processing to synchronise the position of the sample and the scan field. Therefore, the sample can be moved continuously while the scan field of the scanner is continually updated to write a pattern continuously. This technique is called *Sync Scan*.

One of the main advantages of Sync Scan over mask projection techniques is the flexibility of not requiring a mask. The design of the pattern to be produced can be generated using CAD packages and the data file can be directly interfaced with the Sync Scan system. This also allows great freedom in assessing different designs quickly just by altering the code data.

Sync Scan operates by dividing the patterns into rectangular sections where the length of the rectangle is the size of the scan field. The width of the rectangle is typically a few hundred microns in size and the sample stages move along this direction. Therefore, the scanner mirrors scan along the length of the rectangle and the sample stages move orthogonal to this. During the motion, the scanner mirrors are supplied with continuously-updated pattern data so that constant patterning can take place.

Typical scanning speeds of galvanometer mirrors are of the order of a few metres per second and the sample stages move at modest speeds of ~10-20mm/sec. The typical size of a scan field is currently between 20-100mm and this means that positioning accuracies of a few microns can be obtained.

Figure 8 shows an example of the output of the Sync Scan system where an electrode pattern for an inter-connect package has been written into a sample plastic (for demonstration purposes only). The width of the pattern is ~95mm and individual electrodes are ~55μm in width, as shown in the inset. The use of Sync Scan in the manufacture of display devices is likely to be a major application.

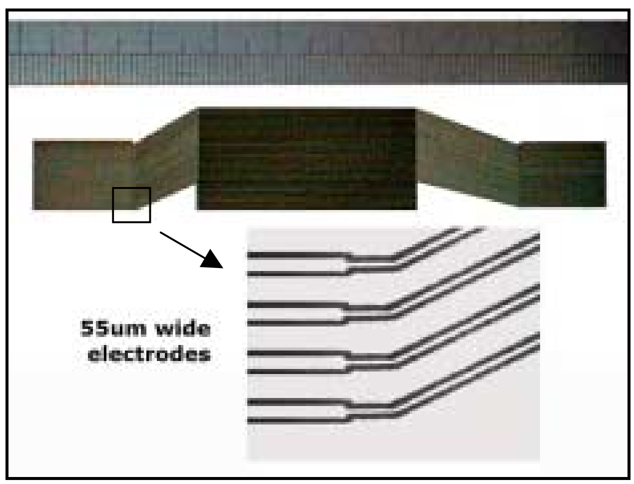

Figure 8. Electrical inter-connect structures for display devices patterned using direct writing with Sync Scan.

The technologies for the various types of displays planned for the next few years are all biased towards the development of larger areas and this can impose severe limitations on their manufacture if only conventional lithography and etching techniques are to be used. The direct patterning of the various layers of the display panels is a very attractive and flexible option as it allows a variety of designs to be produced relatively easily with the same system and the size of the panels which can be processed is only limited by the size of the XY stages.

The Sync Scan approach is also finding industrial applications in the laser drilling of via holes in PCB boards where speed of processing is also a key factor and where the positions of individual via holes is fed into the system through data files.

FUTURE TRENDS

In general, many areas of laser micro-machining applications are increasingly demanding the ability to be able to machine non-planar samples and this challenge is already being taken up by both excimer laser mask projection systems and direct write tools. The problems with this approach are similar, irrespective of the technique which is considered - how to handle a sample with an arbitrary shape, how to maintain proper imaging or focussing on the sample surface and how to program the system to micro-machine the desired pattern with sufficient accuracy. The systems described in this article are all being developed along these lines for the micro-machining of 2.5D or 3D micro-structures.

Other areas of development in laser micro-machining include the use of shorter excimer laser wavelengths (157nm) which can access more materials with better precision (e.g. PTFE) and the use of ultra-short pulses to machine the widest choice of materials with very high quality.

SUMMARY

The techniques of synchronised overlay scanning, which is used with excimer laser mask projection systems, and Sync Scan, which is used with high repetition rate solid-state lasers, have been presented together with application areas where these methods are likely to be used effectively. These micro-processing solutions are a part of the development which is currently taking place in laser-based technologies. These new processing methods are, in turn, helping to fuel the rapid rise in the innovative use of lasers for many diverse, industrial applications.

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