Process Strategies for Excimer Laser Patterning

Projection & Demag.

With rare exceptions, **excimer** lasers are used with **mask projection**, generally with some degree of imaging **demagnification** a) to better match typical process e.d. (energy density) to laser o/p e.d., b) to provide a useful gain in resolution of fine features defined on the mask. We make a distinction between the **imaging system** which is between mask and part, and where it is crucially important to hold those three in a fixed and rigid geometrical relationship(they are often co-mounted on a massive granite base/bridge structure), and the **illumination system**, between laser source, where a precision mechanical relationship is much less important,- the function of the illumination system is simply to manipulate the laser beam to the desired size/shape etc on the mask.

Taper reduces with the increased e.d. resulting from high demag., so typical imaging demag. ranges from 10-25X for ceramics & deep hole drilling to a more modest 2-5X for surface patterning. A typical do-everything system is 10X whilst, occasional applications use 1:1 imaging either with contact masking or optical systems where the symmetry of a 1:1 optical system offers some advantages like elimination of optical distortion and the possibility of using catoptric imaging with,- by definition,- zero chromatic error(Optec has produced such systems based on Offner lenses) .

For **2D patterning**, (i.e. where ablation depth is small compared to feature size) we, like other machine builders, have often settled on a demag of 4-5X. With typical laser o/p energy density of 50-100mJ/cm^2, and allowing for losses, this allows processing up to around 1J/cm^2, using Cr/FS masks with **damage threshold** typically in excess of 70mJ/cm^2.

Such systems can use Optec 4EL copy lens with the demag. under **PC control** according to the **Optec LD principle** over a limited range for fine tuning of pattern size. This unique feature, originally developed for the MM **LightDeck** platform, allows optimum fitting of pattern to suit substrate stretch etc.

Mask Motifs

We distinguish between patterning using **simple/primitive motifs** and **complex motifs**. For us, a simple motif might be a single circle or square, but includes **dynamic motifs** such as can be generated with PC controlled **MRA**(Motorized Rectangular Aperture) with which one can define a rectangle of any size/shape, but not, for e.g. a circle. In a refinement of this idea we have developed the **Optec IA**(Intelligent Aperture) which combines MRA with motorized simple motif selector(for e.g. linear array of different sized circles) and moreover allows the creation of **combination motifs** resulting from truncation of the selector motifs using the MRA,- for e.g. half circle,- and where the resulting virtual motifs are stored in PC memory, practically without limit.

Complex motifs, which unlike stencil-type masks can be other than **simply connected**, are then defined by a Cr/FS mask; refinements include Al/Cr/FS and dielectric masks suitable for high rep. rate work.

Process Strategies for 2D Patterning

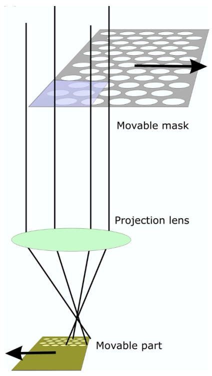
Limiting discussion only to techniques used for **2D patterning**, the optimum strategy to employ depends on the details of the pattern, for e.g.:-

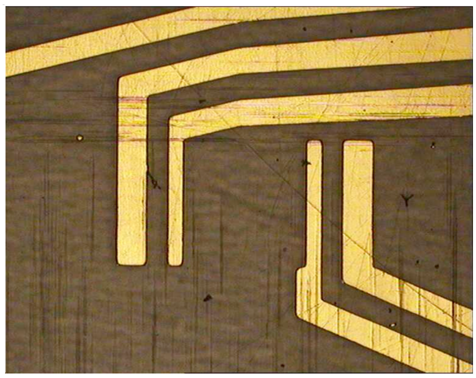
1) **S&R (Step & Repeat);** used where the same motif has to be repeated, usually on a fixed pitch array. The workpiece has to move & settle to the new location before firing the laser for the prescribed number of shots N. Particularly for low shot count typical of 2D processing, system throughput is then mainly a function of stage dynamics.

2) **OTF (On-the-Fly)**; moving the workpiece at constant speed whilst firing the laser using the selected motif, for a single shot using PSO(Pulse Synchronized Output) to ensure the correct placing of each shot. Often used for single shot processes, can also be used for multiple shots simple by repeating the scan,- though inappropriate for N greater than about 10. For e.g., Optec has used OTF extensively for LLO(Laser Lift Off) applications(mostly 1-2 shot). Compared to SR, there is an immediate gain in throughput since accelerations between successive process zones are eliminated. At the highest shot placement accuracies, it becomes impossible to maintain OTF through the acceleration ramp required to run the stage up to constant speed, and for high scan speed the additional stroke required for those acceleration ramps outside the process area can exceed the linear scan stroke.

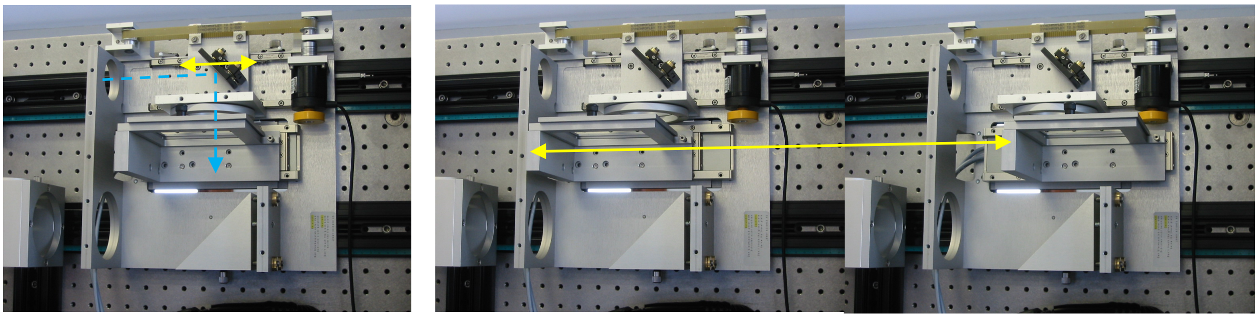
3) **MS (Mask Scanning);** the (non-repeating) pattern on the mask is larger than the laser beam; we form the beam into a ribbon and scan(usually in the short axis) that ribbon over the complete pattern area, so that each location receives N shots average. This an easy and efficient way of processing rectangular areas, since the moving part(a mirror) has much low inertia, and no particularly high precision is required on the position of this illumination component.

4) **OCM (Opposed Coordinate Motion)**: similar to the above, but with a shift of reference frame, and often used where a non-repeating mask pattern is much larger than the area that can be processed at any one time by energy density considerations. OCM requires higher precision stage motion coordination than MS, but allows processing close to the optical axis by keeping the laser beam(and process lens) fixed, and scanning mask and part in synchronization in opposite directions & in the ratio of the demag. Motion is usually at constant speed, laser firing to give average N shots, sometimes using hexagonal premask to ensure uniform shot dose along the join between successive line scans.





These images come from a system equipped for both MS & OCM, patterning of conducting laser on PC, a very small part of the pattern shown above. At left the static mask is scanned by the turning mirror above on a belt driven stage. Centre & right the scan mirror is stationary, and mask scans beneath fixed beam.



5) **SCR (Step, Change & Repeat)**; i.e. as a), but where the pattern may be changed from one process zone to another. There are different possibilities:-

   a. Essentially OCM, but where mask & part come to a halt before firing the laser, rather than operating in a true dynamic OCM mode.
   b. Essentially 1) above but where:-
      i. MI(Mask Indexing) The new motif is selected from a large mask, but not necessarily in a fixed location w.r.t. other motifs, as in OCM;- i.e. one regards the large 2D mask as a library of different motifs, to access at random.
      ii. MS(Mask Selection) for e.g. by loading a new mask. Clearly, one can combine these two, i.e. interchangeable masks, each carrying a number of motifs for MI.
      iii. MM(Mask Modification) for e.g. using MRA or IA;- generally limited to simple motifs. For e.g. if the complete pattern were composed of a number of different shaped motifs which can be generated by IA, and mostly of a size where one needs to use a significant proportion of the beam anyway, then this can be a simple and efficient way to work,- eliminating mask making.

3D Processing

The first step towards 3D processing is deep drilling using higher shots dose, and where aspects like **taper** and **telecentricity** become important. The former is mostly connected to energy density, the latter is a function of the way in which the illumination & imaging systems interact.

For patterning where the features to be produced have a specific 3D shape, for e.g. pyramid or lens arrays, there are more evolved processing strategies:-

6) **OG (Orthogonal Grooving):** the part is moved whilst firing the laser at(for e.g.) a row of motifs. The result is a linear array of grooves on the part. Repeating a similar procedure with the part rotated in theta by 90°(or other) results in a dense array of 3D features, for e.g. rectangular lenslets; see other technotes.

7) In **CS (Contour Sectioning)** one has a mask motif corresponding to the 2D shape of each ablated layer. Obviously, for deep features this might require an uncomfortable number of separate masks, but where a large number of identical shapes are to be processing in a regular array then one can arrange for the separate motifs to be in a row, illuminated by a ribbon beam, and the laser is fired in synchronization with part motion along the row, so that each location receives a single shot from each of the separate motifs leading to **DCS (Dynamic Contour Sectioning**. (sometimes termed **SIS (Synchronous Image Scanning)**.