Excimer laser projector for microelectronics applications

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ABSTRACT

Fully integrated excimer laser mask macro and microprojectors and application workstations that produce on the workpiece illumination uniformities as low as +/-5% with overall energy throughput efficiencies of up to 70% are described.

1. INTRODUCTION

There is an increasing interest in using excimer lasers in microelectronics manufacturing for such processes as wafer annealing, marking, mask and chip repair and interconnect hole drilling. Crucial to these applications is the ability to deliver efficiently to the sample the high UV pulse energy provided by these sources. A common requirement is to produce on the workpiece at a size and pulse energy fluence appropriate for the application an optically demagnified image of a uniformly illuminated mask or aperture. Often the single pulse fluence required is several J/cm² over several tens of mm².

Most commercial excimer lasers produce pulsed rectangular beams with aspect ratios of about 2:1 and areas of ~2cm². With approximate Gaussian and superGaussian spatial intensity distributions in the two orthogonal directions, typically 75% of the total pulse energy shows a spatial rms intensity deviations from the mean of > +/- 35%. For many critical applications such large beam inhomogeneities are unsatisfactory since beam intensity variations usually become replicated into the processed material. The approach often adopted to achieve a better beam uniformity is the very lossy procedure of simply aperturing the beam size. In this case a much larger laser must be used than the application often requires and the area that can be processed in one step becomes severely limited. Various optical beam homogenisation methods use devices like diffuser plates, fly's eye lenses, kaleidoscopes, fibres, mirrors and prisms to break the laser beam up into smaller subcomponents that are then reconstituted together. The energy throughput efficiency provided by such techniques is often also very small (typically <20%). This paper describes fully integrated excimer laser macro and micro mask projectors that produce on the workpiece illumination uniformities that can be as low as +/-5% with overall energy throughput efficiencies of up to 70%. Variable demagnified images of mask patterns can be projected onto reflective workpieces like Si and GaAs wafers over field sizes of up to IN 10mm without incurring damage to the projector optics. Results on their use for various materials processing applications are given.

2. MACROPROJECTOR

Currently excimer lasers are used in production for drilling via holes in polyimide layers in printed circuit boards (PCB's) and multi-chip-modules. A general purpose macroprojector that can be used for R & D work in such areas is illustrated in Fig 1. It incorporates and integrates together a beam homogeniser, a continuously variable beam attenuator, a beam profiler for monitoring the uniformity at the mask plane, CCD camera for sample viewing and projection lenses for variable demagnification imaging of the mask pattern onto the sample.
A continuously variable beam attenuator consisting of a matched pair of dielectric reflective and AR coated fused silica plates that counterrotate to eliminate deflection of the transmitted beam allows the user to readily set and change the illuminating energy fluence at the sample. If necessary its setting can be computer controlled to vary its transmission between 1 - 90% for a particular excimer laser wavelength. Depending on the characteristics of the beam from the laser in use (beam intensity distribution, dimensions and divergences in the two orthogonal directions), a combination of image plane relaying, beam segmentation, overlap and inversion techniques are used in the beam homogeniser to efficiently produce the desired intensity distribution that illuminates the mask plane. Although not always, for most applications a flat top 'top hat' profile is required. For the majority of current applications of excimer lasers being investigated for use in microelectronics manufacturing a critical requirement is a high degree of beam uniformity delivered with a large pulse energy to the workpiece. For setting up the homogeniser and monitoring, analysing and archiving the spatial intensity distribution illuminating and transmitted through the mask, a beam profiler that monitors in real time these parameters on-line is an essential feature of the projector. Fig 2 shows a typical beam profile illuminating the mask plane after homogenisation.
In this case 90% of the total beam energy has rms intensity fluctuations of only +/- 5.4%. Such highly uniform beams on samples are crucial for such potential critical applications as excimer laser annealing of silicon thin film transistors (TFT's), for example. A fused silica field lens is used to collect the divergent radiation near the mask plane and relay it to the mask imaging lens. Depending on the demagnification, resolution and field size of the image required on the workpiece, singlet, doublet or multilens combinations are used to create an image of the mask on the surface of the sample. As shown in Table 1, a range of standard macroprojection singlet and doublet fused silica lenses give various field sizes from 16x16 to 1x1mm with image demagnifications from x16 to x1.

<table>
<thead>
<tr>
<th>Mag</th>
<th>Numerical Aperture</th>
<th>Max Image Field Size</th>
<th>Min Image Size</th>
<th>Max Image Fluence*</th>
</tr>
</thead>
<tbody>
<tr>
<td>x16</td>
<td>0.65</td>
<td>1mm</td>
<td>5µm</td>
<td>40J/cm²</td>
</tr>
<tr>
<td>x8</td>
<td>0.65</td>
<td>2mm</td>
<td>10µm</td>
<td>10J/cm²</td>
</tr>
<tr>
<td>x4</td>
<td>0.5</td>
<td>4mm</td>
<td>10µm</td>
<td>2.5J/cm²</td>
</tr>
<tr>
<td>x2</td>
<td>0.4</td>
<td>8mm</td>
<td>20µm</td>
<td>1J/cm²</td>
</tr>
<tr>
<td>x1</td>
<td>0.28</td>
<td>16mm</td>
<td>20µm</td>
<td>0.25J/cm²</td>
</tr>
</tbody>
</table>

Refractive lenses usable in MacroProjector

Depends on laser type. Assumes ~600mJ/pulse from laser

With these simple lenses, the image resolution can be ~5µm at fluences on the workpiece of up to 40J/cm². Intermediate high fluence projection optics provide field sizes of ~0.25mm and resolutions down to ~3µm at fluences up to 50J/cm². For resolutions of ≤1 µm specially designed multicomponent imaging lenses can be incorporated into the projector. The resolution can be further improved by using a line-narrowed excimer laser source. To maximise the transmission of the projector, all transmissive optics are AR coated with a thin layer of low-loss high laser damage threshold colloidal silica. Photographs of this projector are shown in Fig 3.
Examples of patterns cut in polymers, ceramics and glass obtained with simple lenses in the projector coupled to XeCl, KrF and ArF excimer lasers are shown in Figures 4 - 8.

**Polycarbonate sheet (Lexan)**
Etched with KrF laser at 2.5J/cm²
*Figure 4*

**Zirconia ZrO₂**
Etched with XeCl laser at 15.6J/cm²
*Figure 6*

**Paper Card (Cellulose)**
Etched with ArF laser at 1J/cm²
*Figure 5*

**Silicon Nitride Si₃N₄ (Nipped) Etched**
with XeCl laser at 15.6J/cm²
*Figure 7*
Borosilicate Glass
Etched with ArF laser at 55J/cm$^2$

Figure 8

Demetallisation of ~0.2µm thick copper and aluminium on polyimide (Kapton) sheet
KrF laser at 0.3 J/cm$^2$

Figure 9
The single pulse KrF laser demetallisation patterning of thin aluminium and copper films on polyimide sheet obtained using the projector is shown in Fig 9.

Examples of high resolution ~20µm deep ablatively etches in thin polycarbonate (Lexan) sheet using a x10, 15mm field size, 0.125NA multicomponent lens in the projector with a non-linenarrowed KrF laser source are shown in Fig 10. It can be seen that the resolution for ablative etching with this system was ~1.5µm.

Polycarbonate etched with KrF laser at 248nm (no linenarrowing). A single image of a (multicomponent) resolution test mask. x10 reduction; Resolution ~1.5µm, 15mm field.

Figure 10

When fully integrating the laser and the macroprojector into a radiation-tight interlocked enclosure, the micromachining workstation shown in Fig 11 can be used in more industrial production types of environments.

Excimer Laser Micromachining Workstation
Series 7000 MacroProjector
Figure 11
The workstation incorporates a wafer vacuum chuck and computer controlled variable attenuator and mask aperture size and shape, beam profiling diagnostics and x-y-z stage sample motion and laser control. If required, all can be operated and linked together under fully Computer Numerical Control (CNC) generated by CAD/CAM codes in DXF or HPGL files.

For applications in the fabrication of thin films (principally of high temperature superconducting copper oxide materials) by excimer laser ablative sputtering of sintered targets, it is known that to achieve high quality film deposition which replicates the material stoichiometry of the target the incident laser energy fluence is critical. A well defined fluence of a few J/cm² over several mm² on the target is ideally required in a 'top hat' type of distribution with a uniformity of <±10%. An excimer laser ablative sputtering system that efficiently produces this type of target irradiation onto an angled target for depositing thin films of mixed compound materials is shown in Fig 12 and is a variant of the macroprojector workstation shown in Fig 11.

![Excimer Laser Ablative Sputtering Workstation](image)

**Figure 12**

**3. MICROPROJECTOR**

As shown in Fig 13, to obtain higher submicron resolutions (at the expense of reduced field size) a suitably illuminated reflective Schwarzschild objective can be used for imaging in the projector. Such a projector with a computer controlled simple variable aperture as the mask is appropriate for example in applications to lithographic mask and chip repair. Since an all-reflective objective does not introduce chromatic aberration to the projected image line narrowing of the laser source is not necessary to produce high resolution and a white light lamp source can be used to illuminate both the aperture and the workpiece through the objective so that the focussing and targeting with the aperture window can be viewed simultaneously in real time with a CCD camera. This type of objective also introduces no astigmatism, coma or spherical aberration to the projected image.
As summarised in Table 2, objectives with demagnifications ranging between x 15 to x74 can be used in the projector to produce image field sizes ranging between 1x1mm and 1x1µm. Image resolution can be as high as 0.5µm with illumination fluences on the sample of up to 40J/cm².

<table>
<thead>
<tr>
<th>Mag</th>
<th>Numerical Aperture</th>
<th>Max Image Field Size</th>
<th>Min Image Size</th>
<th>Max Image Fluence*</th>
</tr>
</thead>
<tbody>
<tr>
<td>x74</td>
<td>0.65</td>
<td>0.2mm</td>
<td>0.8µm</td>
<td>100J/cm²</td>
</tr>
<tr>
<td>x52</td>
<td>0.65</td>
<td>0.3mm</td>
<td>0.8µm</td>
<td>50J/cm²</td>
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<tr>
<td>x36</td>
<td>0.5</td>
<td>0.4mm</td>
<td>1µm</td>
<td>25J/cm²</td>
</tr>
<tr>
<td>x25</td>
<td>0.4</td>
<td>0.6mm</td>
<td>1.5µm</td>
<td>10J/cm²</td>
</tr>
<tr>
<td>x15</td>
<td>0.28</td>
<td>1 mm</td>
<td>2µm</td>
<td>5J/cm²</td>
</tr>
</tbody>
</table>

* Reflective Objectives useable in MicroProjector

* Depends on laser type. Assumes ~200mJ/pulse from laser

Table 2

Fig 14 shows an image of the rectangular aperture used for targeting and cutting a 7µm wide aluminium track on a silicon chip using the x36 objective in the projector. Fig 15 shows a demetallised KrF laser cut track in ~0.05µm thick gold film produced by raster scanning a 20 x 60µm image of the mask aperture.
An example of a resolution test pattern image cut into polycarbonate sheet to a depth of ~0.5µm with a single pulse from a KrF laser with this objective is shown in Fig 16. The high resolution capability of this projector is demonstrated by observing that the narrowest lines etched are 0.55µm wide. Fig 17 shows the steep wall angles obtained with the microprojector when cleanly cutting a ~5µm deep image of a cross mask with 10µm wide bars into polyimide film.

Because the reduced image field size does not require the full excimer laser pulse energy, this projector is also well suited for use with lower pulse energy 4th harmonic Q-switched Nd:YAG laser radiation at 266nm.
When fully integrating the laser with the microprojector in a stand alone enclosure, the micromachining workstation shown in Fig 17 can be used in more production types of environments.

![Excimer Laser Micromachining Workstation Series 5000 MicroProjector Figure 17](image)

Like the Series 7000 macroprojection workstation shown in Fig 11, the system (laser, attenuator, aperture size, stage motions) can be operated under full CNC control.

4. SUMMARY

Two types of mask projectors for general purpose microprocessing applications with excimer lasers are described. The first is a macroprojection system incorporating refractive imaging lenses, beam homogeniser variable attenuator that produces uniformly illuminated demagnified images with resolutions down to ~10µm over field sizes of up to 10x10mm. The second uses a Schwarzschild reflective objective to achieve submicron resolution imaging with sample viewing and targeting as appropriate for mask and chip repair. Such devices can be fully integrated with the laser to provide workstations for a variety of applications in the microelectronics and other industries.

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5. REFERENCES

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