DIGITAL PROJECTION OF UV LIGHT FOR DIRECT IMAGING APPLICATIONS, DLP® TECHNOLOGY IS ENABLING THE NEXT GENERATION OF MASKLESS LITHOGRAPHY

August 18, 2008

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INTRODUCTION:

Maskless Lithography, also known as Direct Imaging, of products like semiconductors and PC motherboards has significant advantages in terms of cost savings and flexibility compared to traditional lithography that involves the use of masks to image patterns onto photo resist. The topic of maskless lithography has been around for years, but early generations of maskless lithography machines, which use a “flying” laser spot, have not been able to match the throughput of traditional lithography machines and the critical feature size, at the same time. DLP® Technology offers a way to project ultraviolet (UV) light digitally so that it is no longer necessary to trade-off flexibility of quick product changes, manufacturing speed, and critical feature size.

This article introduces DLP® technology, how maskless lithography can be done using a Digital Micromirror Device (DMD™), the advantages of this new approach, and the reliability of the DMD™ in UV applications.

DLP® TECHNOLOGY:

The DMD is an optical semiconductor, a Micro Optical Electronic Machine (MOEM).

Figure 1. The Digital Micromirror Device (DMD™)
One DMD contains a rectangular array of up to two million hinge-mounted microscopic mirrors, each of these micromirrors measures less than one-fifth the width of a human hair.

![Micromirrors in a DMD](image)

**Figure 2.** Close-up of the micromirrors in a DMD™.

DLP® Technology has been shipped into over 16 million units of Digital Cinemas, HDTVs, and Digital Projectors. Now, the DMD is being made available for applications that use ultraviolet light. While other MEOMS devices have been announced for UV applications, the DMD is the only MEOMS that is in high volume production and offers a reliability with UV light.

**THE CONCEPT OF MASKLESS LITHOGRAPHY WITH DLP® TECHNOLOGY.**

With conventional lithography machines, a product like a layer of a PC motherboard is imaged in one machine. Then the next level is imaged in another machine, etc. Each machine on the manufacturing floor is configured with a different photo-mask and is one step in the manufacturing process. Maskless Lithography has been discussed for years because of its promise of lower costs and increased flexibility. Most of the cost savings comes from avoiding the costs typically associated with mask creation, storage, maintenance, inspection, and correction. In addition to material costs, the labor costs associated with these processes can be avoided as well.

Maskless Lithography also offers increased flexibility because a machine can quickly be loaded or configured with a new design, there is no need to create and install a mask set. The same machine could be used to image multiple layers, instead of using one machine per mask. Moreover, for semiconductor manufacturing, different products could be combined onto the same wafer. This kind of flexibility facilitates rapid prototyping and dramatically speeds time to market.

DLP® technology enables lithography systems that match the throughput of traditional contact exposure (masked based) systems. Moreover, by using UV light, conventional photo resist can be used.
Figure 3. A Maskless Lithography System using DLP® Technology

Figure 3 shows how DLP® Technology can be used for maskless lithography. An ultraviolet light source (lamp or laser) illuminates the DMD. The DMD has up to two million mirrors in an array that are illuminated in parallel. The mirrors create the pattern that is to be projected onto the substrate. The image is projected through the output optics and onto the photo resist. By putting multiple DLP® projection paths in parallel, fast throughput can be achieved.

COMPARISON OF DLP® BASED LITHOGRAPHY WITH FLYING LASER SPOT

Traditional maskless systems typically expose or process by way of a “flying” laser spot. The output of a laser beam is focused down to a spot equivalent to the smallest dimension in the desired pattern; the critical dimension. This spot is then raster scanned, generally using two oscillating mirrors, across the material while the spot intensity is modulated.

In these “flying” laser spot machines, throughput is limited by both the desired minimum feature size (equal to the spot size) and the amount of power that can be focused into this flying spot. The more power, the faster the spot can be moved over the material while
still meeting the required amount of photonic energy required to activate the photo resist, however, the critical dimension tends to be limited at higher power and speeds. Power is generally limited by the power handling capabilities of the beam shaping optics. Imperfections in the optics create absorption zones that can lead to overheating and cracking. For example, in some systems, a single piece of dust landing on an optical element can create enough absorption to cause a failure. In contrast to that, a DLP® based maskless lithography system is much more robust. The light from the laser is rapidly expanded to fill the entire mirror array. From that point forward, the beam travels through a wider optical path, right up until the final reduction lens, which concentrates the DMD image on the material. This technique results in a robust and reliable system.

In addition to the robustness of the DLP® projection scheme, using a laser illuminated DMD image instead of a flying spot helps break the tradeoff between resolution (critical dimension size) and power. With a flying spot scanning laser system, very small spot sizes can be realized and very high throughput can be realized, but it is difficult to do both at the same time. At lower power levels, a flying spot system operates more slowly than a conventional masked-based lithography system.

With a DMD, an area millions of times larger than the critical dimension is illuminated, enabling efficient usage of very high light source power. High speed control of individual mirrors enables precise control of power levels at the critical dimension. And at any one time, the light projected by the DMD can cover a larger area on the material being processed than the flying spot based system. The more power the system can bring to the material, the faster the material can be processed. Therefore, DLP® based maskless lithography systems are fast and can match the speed of traditional mask based lithography systems.

The traditional mask based lithography systems expand a light source and illuminate large aperture mask. Therefore, they share similar optical reliability advantages as a DLP® based maskless lithography system (the light path is not passing through tightly focused beam shaping optics). The masked based machines and the DLP-based maskless lithography systems share the advantage of the decoupling of critical dimension and illumination area size, which leads to good power and high throughput.

**UNIQUE CAPABILITIES FOR DLP® SYSTEMS**

There are many other unique capabilities that DLP® technology offers to these traditional masked based systems. Fixed mask systems must step and repeat the same image across the material because the mask is a passive component. A DLP® based maskless lithography system can change the “virtual mask” image on the DMD in tens of microseconds which is fast enough to keep pace with high speed Q-switched lasers. This means that the system can expose a unique image or “virtual mask” based on its position over the material. This ability allows DLP® systems to implement a wide variety of unique imaging schemes such as:

- Continuous scanning with overlapping exposures
Gray scale generation (gray scale lighography)
A wide variety of scan line seaming techniques, and
Multi-pass laser pulse time averaging in a single pass

Both laser spot scanning and traditional step and repeat mask systems are sensitive to variations in source laser output power. But, the ability of DLP® systems to overlap images allows for time averaging of the illumination pulses, without resorting to multiple passes with a scanning or stepping mechanism.

To maximize speed, a typical DLP® system will employ a large array of DMDs and reduction imaging optics to enable processing speeds that match or, in many cases, exceed that of traditional fixed mask systems. A DLP® system combines the best of all of the technologies – the speed of a mask based system, the flexibility of a flying spot based system, and the numerous unique advantages listed above.

Lithography is one of the first industrial material imaging applications to embrace DLP® technology. But, the extraordinary power handling capabilities of the DMD enables its use in a wide array of industrial laser material processing applications which include, but are not limited to the following:

- Photo ablation (advanced packaging, MEMS micro-machining, photo mask repair, LCD panel repair, memory repair, color filter repair, ITO patterning, through silicon via drilling, inkjet formation, stent fabrication, micro-fluidics, micro-optics, medical applications like tumor treatments and eye surgery)
- Laser direct write (laser induced forward lift, laser induced backside etch, integrated passive device deposition, direct circuit patterning – “intennas”, flexible electronics)
- Auto-defect detection and correction (LCD-TFT, OLED, solar, flexible electronics)
- 4D structured annealing (lateral crystal growth - TFT, OLED, solar, copper annealing, IC poly-silicon)
- High speed, automated micro-trimming
- Micro-welding
- Micro-drilling
- Metal etching
- Micro-scribing (chip scale package marking, wafer marking, passive component marking)
- Selective sintering (3D printing, medical models)
- Medical surface treatments (selective phototherapy, tattoo treatment)
- 3D structured lighting (high resolution metrology, wafer inspection, pixilated reticle illumination)

A new era in industrial material processing is here, enabled by DLP® Technology.
DMD® RELIABILITY WITH UV LIGHT

One significant advantage of the Digital Micromirror Device (DMD™) is that it is a very reliable MOEM structure in the visible region of the illumination spectrum. In fact, DLP® Products has shipped over 16 million DLP® chipsets since 1996 for conventional display applications such as front projectors, HD TV’s and Digital Cinemas. Under normal operating conditions, the DMD pixel has a lifetime of over 100 thousand hours 400 to 800 nm wavelength illumination. Under 400nm illumination, the DMD is the only spatial light modulator (SLM) that can serve this market today.

We all know the effects of Ultra Violet (UV) light on human skin. It ranges from some benefits such as production of vitamin D to damaging effects such as sunburn and skin cancer depending on wavelength, power density and length of exposure. This is a clear evidence of UV interaction with organic matter. The DMD™ is mainly a metal structure built using standard semiconductor processes. Therefore, it is less susceptible to UV illumination than other SLM’s that use active organic materials such as Liquid Crystal Displays (LCD).

Texas Instruments has been evaluating the DMD performance under UV illumination for several years. In fact, the DMD is being used today in applications using UVA illumination such as lithography at 365nm. For the purposes of this article, we have defined failure of the DMD as less than 30% reflectivity degradation under the listed conditions.

Table 1 shows a comparison of two assembly processes evaluated for use in UVA applications. Data shows an estimated lifetime of 4000 hours for our current products (Process A) and more than 8000 hours of continuous exposure for our new product that is under development (Process B).

<table>
<thead>
<tr>
<th>Process</th>
<th>23C</th>
<th>30C</th>
<th>45C</th>
<th>Estimated lifetime at 23C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Process A</td>
<td>~1%</td>
<td>2%</td>
<td>7%</td>
<td>4000h</td>
</tr>
<tr>
<td>Process B</td>
<td>0%</td>
<td>&lt;1%</td>
<td>&lt;1%</td>
<td>&gt;8000h</td>
</tr>
</tbody>
</table>

Texas Instruments is currently developing new DMDs that last even longer using shorter wavelengths. Table 2 shows a comparison of a new DMD under development for use in UVA applications down to 320nm illumination. Preliminary data suggests an estimated lifetime of at least 2000h at 30C and about 3W/cm2.

<table>
<thead>
<tr>
<th>Process</th>
<th>Reflectivity degradation post 500h at 320-390nm illumination at different temperatures.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Process A</td>
<td>~1%</td>
</tr>
<tr>
<td>Process B</td>
<td>&lt;1%</td>
</tr>
<tr>
<td>Wavelength Range</td>
<td>23°C Lifetime</td>
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<tr>
<td>------------------</td>
<td>---------------</td>
</tr>
<tr>
<td>355-390nm</td>
<td>0%</td>
</tr>
<tr>
<td>320-390nm</td>
<td>5%</td>
</tr>
</tbody>
</table>

Texas Instruments continues to evaluate lower wavelengths and develop new DMDs that are reliable into the UVB and UVC illumination spectrum in order to enable not just maskless lithography, but medical applications like photo-therapy and more.

CONCLUSION

DLP® Technology based maskless lithography systems can have the flexibility of flying laser spot systems, but with the throughput and power efficiency of a traditional masked based lithography systems. DLP® technology has several unique advantages like continuous scanning with overlapping exposures. And finally, the DMD™ is reliable in UV light and Texas Instruments has a roadmap to continue increasing reliability down into the deep UV illumination spectrum to continue enabling new UV illumination based applications.

WANT TO LEARN MORE?

Companies that have recently introduced maskless lithography equipment based on DLP® Technology include BasysPrint, DaiNippon Screen, Hitachi Via, FujiFilm, and ORC. For development options, please see www.dlpdiscovery.com.