Laser-based microstructuring of material surfaces

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Surface materials can be micropatterned using a laser-based technique and low-cost microlens arrays for efficient, low-cost manufacturing.

The modification of surfaces at micrometer and sub-micrometer scales is a key future manufacturing technology. This has led to increasing interest in the creation of micro- and nanometer-sized structures on surfaces, with aims toward enhanced tribological performance for diverse applications including micro-electronics, laser micro-machining, and materials processing. Most laser-assisted microstructuring studies deal with the selective ablation of material. Laser ablation has the advantage of great versatility, as it can be adapted to produce a wide range of structures. Lasers have also proven useful for rapid surface microstructuring and modification of materials, enabling the creation of textured surface features without the bulk material properties being significantly affected or altered.

We developed a laser-based technique for micropatterning material surfaces using low-cost microlens arrays. These arrays offer a unique enabling technology in critical domains including sensing, communications, metrology, and medical imaging, often providing solutions where other technologies prove unsuitable, unwieldy, or cost prohibitive. The use of microlenses is particularly well suited for rapid manufacturing, optimization of laser beam delivery, and improvement of production efficiency with the intention of cost reduction. We fabricate our microlens arrays on soda-lime glass using a laser direct-write technique, followed by a thermal treatment. This method is rapid and simple, and it enables the fabrication of inexpensive microlenses.

Our laser set-up consists of a Q-Switch neodymium doped yttrium orthovanadate (Nd:YVO₄) laser operating at 1064nm, combined with a galvanometer system for moving the output laser beam: see Figure 1(a). A flat-field lens with an effective focal length of 100mm provides a uniform irradiance distribution on a glass substrate over an area of $80 \times 80\text{mm}^2$. Each cylindrical structure is obtained by the ablation of a circular trench, which is formed by moving the laser beam (using the galvanometer scanning mirror system) relative to the stationary glass sample.

We apply a thermal treatment after laser exposure to improve the optical quality of the microlens array by reducing the surface roughness and changing the curvature of the initial post. By combining a laser direct-write with a thermal treatment, it is possible to obtain high quality elements using an infrared laser. Since infrared lasers are already widely implemented in the manufacturing industry, this technique is attractive compared

Figure 1. a) The neodymium doped yttrium orthovanadate (Nd:YVO₄) laser set-up and b) an image of a microlens array obtained using a SENSOFAR 2300 PLµ microscope.

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to other more expensive methods. We used a confocal microscope to obtain the topography and sizes of the elements: see Figure 1(b). The roughness was determined using a contact profilometer.

To demonstrate the structuring capabilities of microlens arrays, we fabricated an array of holes on different material surfaces including stainless steel, copper, aluminum, and polymers. Using microlens arrays enables the simultaneous fabrication of a large number of identical structures, resulting in a highly efficient process. We obtained a $200 \times 200$ array of holes on the material surface. Each hole corresponds to the interaction of light at the focal plane of the microlens over the target material. We analyzed the topography of the fabricated holes using a confocal microscope and a scanning electron microscope. Figure 2 shows a minimum diameter of $3 \mu$m for the individual microstructures generated at the surface. For these applications, we used nanosecond lasers operating at infrared and green wavelengths. The main disadvantage of this process arises from the durability of the microlens, which is strongly limited by the soda-lime glass material, the impurities contained on it, and any imperfections generated during the fabrication process. However, this surface texturing technique works well at low energies, and there is high potential for fabricating microlenses using other high-quality optical materials.

In summary, the microstructuring capabilities of our low-cost microlens arrays have been demonstrated by the fabrication of an array of holes on the surface of several different materials. We are currently working with other glass materials, including borosilicate, fused silica, and sapphire, to improve the durability of the microlenses.

![Figure 2](image-url)

**Figure 2.** (a) Scanning electron microscope image of the array of holes fabricated over stainless steel and (b) image of selective elimination of an aluminum layer over glass, obtained using an optical microscope.

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**References**