High contrast gratings for 3D additive manufacture

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In recent years, 3D printing technologies have made significant progress. Among them, an additive manufacturing process based on fiber optical cable, UV light source and UV curable resin was newly developed (Figure 1), which has advantage in building conformal features on curved surfaces over uniform-layer-based accumulation process. However the fabrication resolution is determined by the size of curing tools which is the diameter of the exit of optical fiber. Small tool gives higher resolution but low throughput. Big tool has high process speed but low resolution. Moreover, most 3D object only needs high-resolution patterning near the surfaces of the object. Therefore multiple tools are necessary. But some problems are introduced such as alignment between patterns fabricated by different tools and additional time is needed for changing tools.

We proposed to solve these issues by spatially modulating of light beam that comes out of a single optical fiber. By using multiple wavelengths in the system, light beams of different wavelengths can have different cross-section patterns and, as a result, have different pixel size (Figure 2).

In this work, the selective aperture is achieved by high contrast gratings which have emerged as an optical device with extraordinary properties. It can transmit or reflect light in designed band with very high (>99%) transmission or reflectivity.

Our device with high contrast gratings on designed area of its surface will be mounted at the exit of an optical fiber. In aforementioned 3D printing system, 365 nm and 405 nm wavelengths of UV light can be used to cure resin. Finally, light beams of the two wavelengths can have different sizes and patterns, which improves the functionality of a single curing tool.

Numerical simulation has shown good performance of the designed high contrast gratings(Figure 3) in which the transmission at 405 nm wavelength is almost zero while at 365 nm it is above 80%. Because of its high refractive index and low lose, TiO_2 is selected to be grating material. The fabrication process is based on nanoimprint lithography and interference lithography. One dimensional grating mold was first fabricated using interference lithography and nanoimprint lithography (Figure 4a). Then the 2-D high-contrast grating structure was fabricated by nanoimprint lithography twice in orthogonal directions using the same grating mold (Figure 4b).

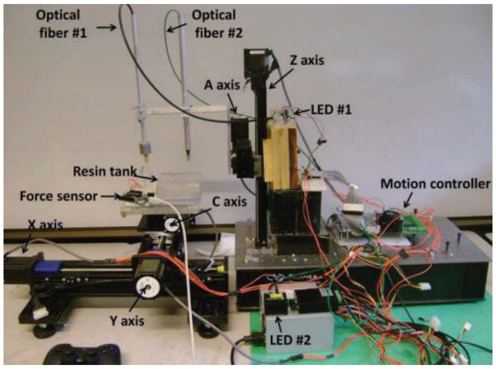

Figure 1: The hardware setup of an additive manufacture system. During manufacture process, the curing tool, which is an optical fiber, is submerged under the UV curable resin. The curing tools have multi-axis motion which is beneficial for fabrication of conformal features on curved surfaces. The high contrast gratings in this work can combine at least two tools into one and increases flexibility of fabrication process.

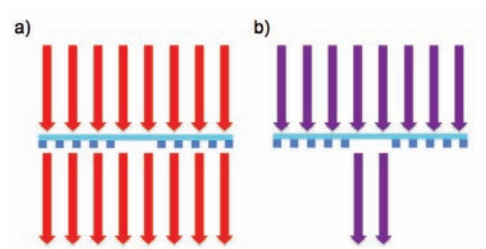

Figure 2: Schematic of spatial modulation of light by high contrast gratings. a) For 365 nm wavelength, light can pass through all area. b) For 405 nm wavelength, it works as a small aperture. Due to high reflectivity of the gratings, light can only pass through designed area where doesn't have gratings.

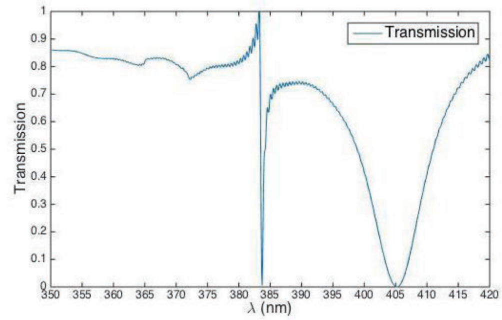

Figure 3: Numerical simulation of transmission spectrum of the high contrast grating by FDTD method. In this case, gratings are two dimensional and have pitch of 245 nm, height of 300 nm and width of 140 nm. The transmission is 82% at 365 nm wavelength while it is nearly zero at 405 nm.

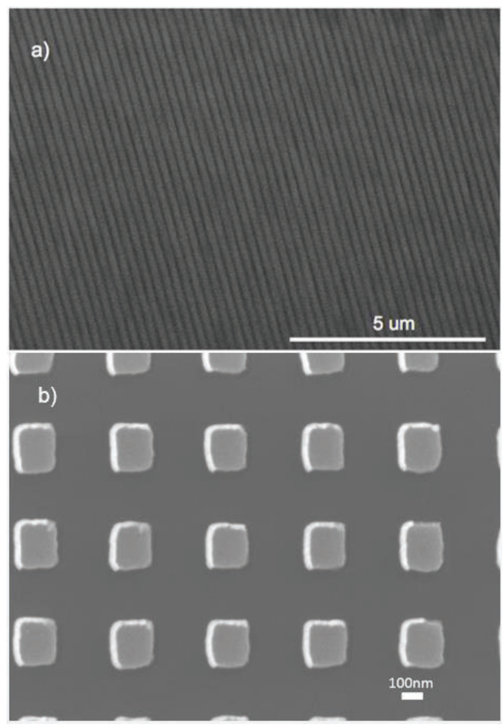

Figure 4: SEM image of a) 1D TiO_2 gratings on fused silica substrate and b) 2D chrome etching mask for fabrication of 2D gratings