Bio-Inspired Multi-Scale Structure for Fluid Drag Reduction Enabled by Variable Voxel Stereolithography

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There are plenty of structures in nature which people can utilize for daily applications. A good example is the skin teeth on fast swimming sharks which serve multi-purpose. They prevent sharks from biofouling and, more importantly, reduces fluid friction drag making the swimming more efficiently through water. Such structure can also be applied to ships and aircrafts with relatively flat sides for which friction drag accounts for a major part of total drag. In past studies, many structures that mimic shark skin teeth have been made through careful machining or molding method. It has been shown that up to 10% drag reduction can be achieved[1]. However, mainly due to the limited resolution in fabricating 3D structures, optimal structures haven't been achieved using these techniques.

Stereolithography is a promising technology to produce customized 3D structures. W. Li et al. have used 3D printer to create enlarged skin teeth[2]. However, the resolution didn't allow the researchers to study the effects of structures at the real scale of shark skin. The limits of current commercially available 3D printing technologies come from a trade-off between throughput and resolution due to the limit of the total number of voxels that can be handled practically.

Last year, we reported a stereolithography technology, which has both better resolution and throughput, with variable laser beam sizes, in a way similar to shaped-beam electron beam lithography. In this work, we applied this technique in building multiscale objects with shark skin teeth. This is realized by a subwavelength grating filter that was fabricated by nanoimprint lithography. The filter has different transmission modes at the two wavelengths (Figure 1). For 445 nm laser, it is transparent and therefore gives a large beam size for fast curing interior space. For 405 nm laser, only a circular area of 25 um diameter on the filter is transparent which gives a small laser spot size for high resolution skin teeth features. As a result, our stereolithography machine is able to deliver sub-50 um resolution while improving throughput about five times.

Different structure geometries that mimic skin teeth have been fabricated (Figure 2-4). The objects in figure 3 and 4 are cylinder shape that is convenient for fluid drag test. The testing is done at the water channel facility on USC campus. The details and further optimization will be reported.

1. Phil. Trans. R. Soc. A 2010 368 4775 4806; DOI: 10.1098/rsta.2010.0201.
2. J. Exp. Biol. 2014 217: 1656-1666; doi: 10.1242/jeb.097097

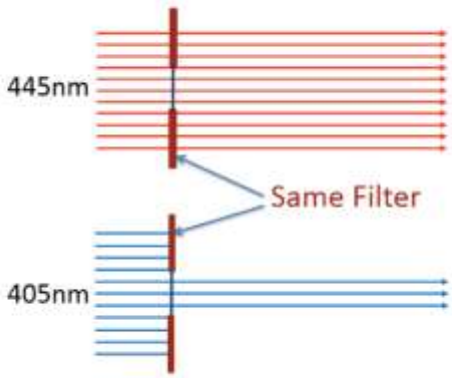

Figure 1: Two transmission modes of the optical filter. For 445 nm light, all light gets through. For 405 nm light, most light is reflected and only a beam with small diameter passes.

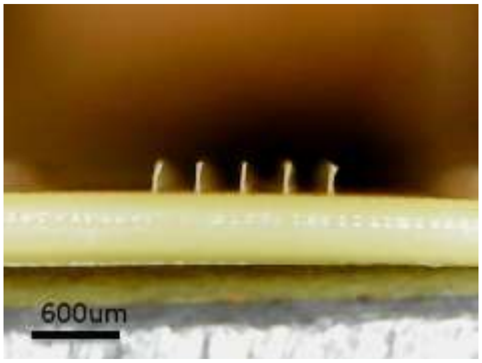

Figure 2: A sample with straight blade riblets that demonstrates multiscale printing capability. The riblets have a pitch of 300 um and wall thickness of 40 um.

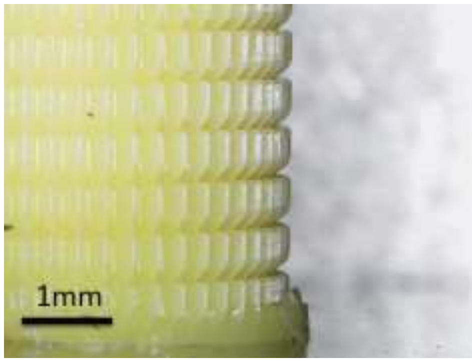

Figure 3: Cylinder with segmented straight riblets.

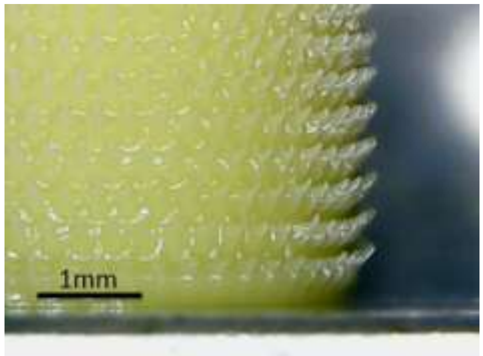

Figure 4: Cylinder with denticle structures.