A Microscale Flow Sensor Sculpted on a Fiber Tip by Multiphoton Polymerization Process

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This work presents a microscale flow sensor fabricated onto the cleaved end of an optical fiber by multiphoton polymerization of a photo resin. A dynamic structure was created with a rotor moving around a stator in response to incident fluid flow (Figure 1). Gold-coated flats on the bottoms of the blades passed over the center of the optical fiber as the device span. The 1550 nm laser input was reflected back down the core when the blades passed over it and recorded by a digital oscilloscope. The flow speed was determined by counting the reflection peaks over 0.5 seconds. An excerpt of this response is seen in Figure 3.

The velocity of the flow impinging on the blades is proportional to flow rate. Higher velocity creates higher pressure when the flow is stopped by the device. This pressure creates a moment about the center of the device that is counteracted by the drag of each blade through the air and the friction of the rotor around the stator. Thus, at a steady state near the nozzle aperture, the rotational velocity of the rotor directly relates to the flow rate. Nitrogen was used to test the flow sensor. The device was placed 4 mm away from the nozzle and aligned with a mirror mount. The flow was varied from 9 to 24 LPM.

The device was fabricated as outlined in previous work,[1] and highlighted in Figure 2. Photoactive resin was deposited around a cleaved fiber face to encompass the build volume. A femtosecond laser was scanned through the resin layer by layer to solidify the desired structure. The non-polymerized resin was washed away. This fabrication process enables rapid prototyping with 3-D design freedom with submicron resolutions. The flow sensor presented was fabricated with 0.2 μm resolution in the x and y dimensions, and 0.3 μm resolution in the z direction. The laser scan to fabricate the entire structure was completed within 5 minutes.

This work successfully demonstrates remote, optical sensing of incident flows using a monolithically integrated 3-D microstructure that occupies a very small volume on an optical fiber tip. The device was characterized from 9 to 24 LPM, and changes as small as 0.165 LPM were measured. This microscale flow sensor highlights the versatility of multiphoton nanomachining and presents a wide range of operation with fine resolution in a small and light package.

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[1] J.W. Smith, J.C. Williams, J.S. Suelzer, N.G. Usechak, and H. Chandrahalim, J. Micromech. Microeng. **30**, 125007 (2020).

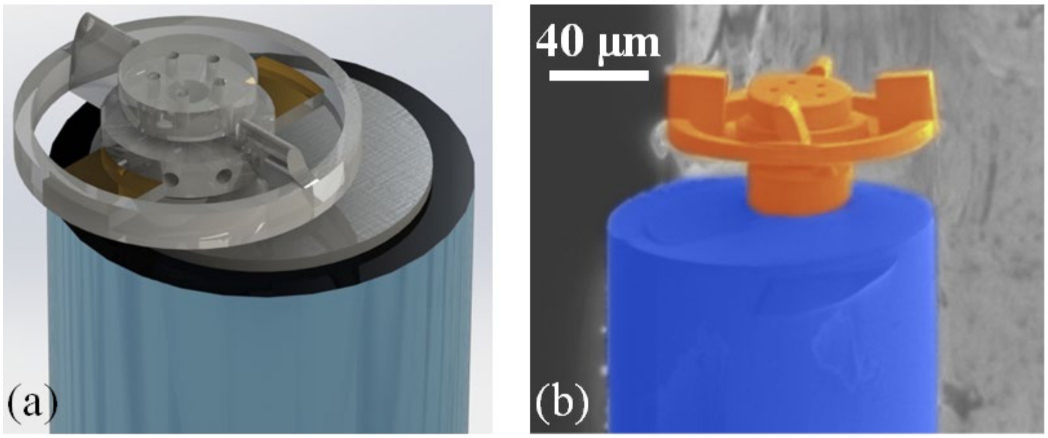

Figure 1: A Microscale Flow Sensor: (a) 3-D Schematic and (b) false-colored scanning electron micrograph (SEM) of the fabricated device.

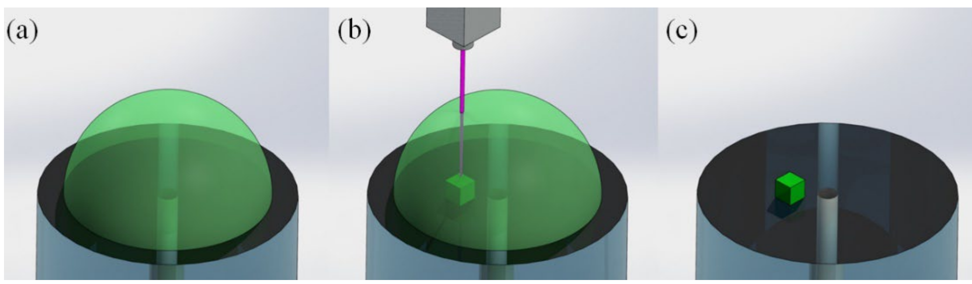

Figure 2: Fabrication Process: (a) Uncured resin, (b) laser polymerization of the desired geometry, and (c) final solid structure.

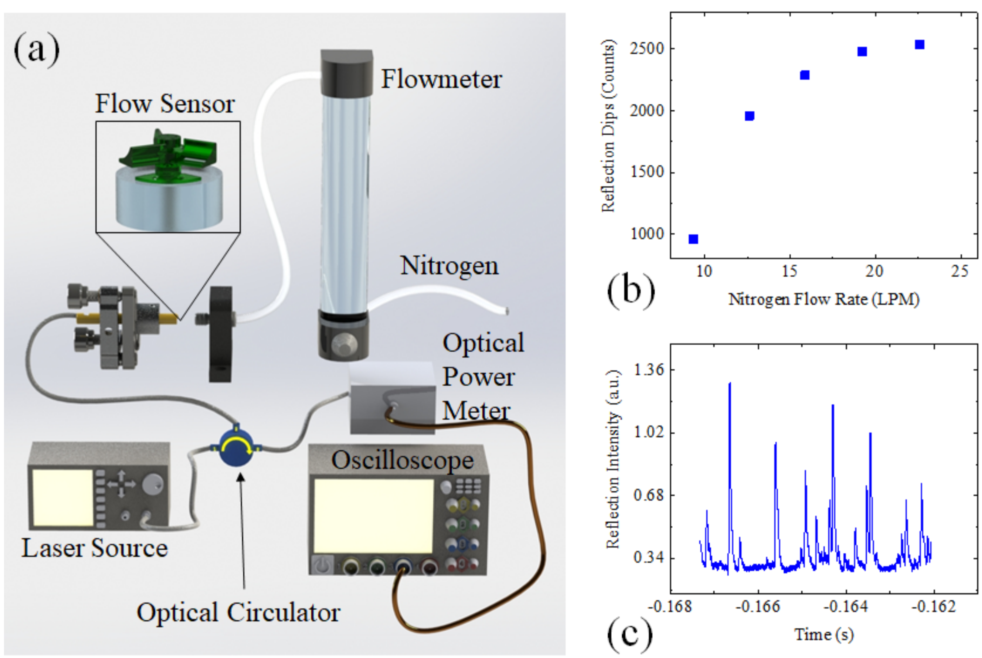

Figure 3: Results: (a) Experimental setup, (b) flow measurement results, and (c) reflection peaks while the device was spinning.