Fabricating in-line fiber etalons efficiently

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Laser micromachining creates an etalon with a self-enclosed cavity inside an optical fiber.

Micro-air-gap-based extrinsic Fabry-Perot interferometers (EFPIs) are used for a variety of applications in sensing and communications, and are typically made by manual cleaving or hydrofluoric acid etching. They offer a number of useful properties including in-line operation from an all-fiber device, compactness, and good temperature stability. Mass-producing EFPIs is difficult, however, because the process involves manual alignment, assembly, and adhesion. This increases the cost and variability between devices.

We report the first demonstration of a fiber in-line etalon with a self-enclosed cavity that has excellent characteristics. This etalon is fabricated using 157nm laser micromachining. Its properties include excellent interferometric fringe visibility of up to ∼30dB, which we believe is the best visibility yet reported for an all-fiber in-line etalon. It also offers great mass-production potential: good reproducibility and low cost are possible because the laser micromachining process can be automated. Finally, this etalon design offers excellent temperature stability.

The 157nm laser micromachining system consists of a pulsed laser, an optical focusing system with 25 × demagnification, an observing system, and a precise translation stage system (see Figure 1). Because the 157nm source has high single-photon and pulse energy and a high absorption coefficient for many materials, it offers ideal characteristics for high quality micromachining.

The process of forming the self-enclosed fiber Fabry-Perot (FP) cavity is shown in Figure 2. First, a circular micro-hole with a typical depth and diameter of tens of micrometers is made at the tip of a cleaved optical fiber by the 157nm laser. Next, an in-line FP cavity is enclosed by simply splicing the first fiber to another cleaved fiber. Hence, such a micro etalon can be operated in high temperature environments of up to ∼800°C and the self-closed structure makes the etalon robust, stable, and reliable. It is also insensitive to temperature change due to the hollow core structure of the etalon and the ultra low thermal expanding coefficient of silica. In addition, the symmetric circular micro-hole means that the device is polarization independent.

Drilling a micro-hole with a depth of ∼30µm at the fiber tip took 160 laser pulses—and only 8s—to complete. From Figure 2, we can see that the roughness of the two reflective surfaces is determined by the quality of cleaving and laser micromachining. The 3D structure of the circular micro-hole was measured as shown in Figure 3. The average and root mean square roughness (Ra and Rq) of the bottom surface of the micro-hole were 335.21nm and 405.65nm, respectively. This shows that 157nm laser micro-machining can achieve a mirror-like surface on the tip of an optical fiber.

An optical microscope and a scanning electronic microscope (SEM) provide photos of the self-enclosed etalon (see Figure 3). Both the two reflective surfaces are parallel and the outside of the etalon is well fused. The reflective spectrum of the etalon is shown in Figure 4. The etalon has a remarkable fringe visibility

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Figure 2. Fabrication process of the self-enclosed FP in-line etalon within an optical fiber. (a) UV laser pulses drill a circular micro-hole at the fiber tip using a 157nm laser. (b) The fiber with the micro-hole is spliced to another cleaved fiber. (c) The FP etalon is completed after an arc-fusion splicing operation.

Figure 3. The micro-hole and etalon. (a) 3D structure of the micro-hole machined at the fiber tip. (b) Photo of the etalon (acquired by an optical microscope in a transmission mode). (c) SEM photo of the etalon.

Figure 4. Reflective optical spectrum of the etalon.

of ~30dB, which is much higher than that of conventional EFPIs that are assembled manually (typically ~15dB). This visibility ensures high accuracy wavelength reference or strain measurement.

We investigated the temperature and strain characteristics over a wide temperature range for both sensing and tuning the wavelength reference to a standard value. Our experiments show that such an etalon has a strain coefficient of 0.1276nm/µε, and a temperature coefficient of 0.015nm/°C. The etalon can be used for strain measurement without temperature compensation in normal environments. In addition, its working wavelength can be tuned by changing the strain applied to it.

Such a microscopic fiber etalon could replace widely used electrical strain gauges in the future, with a large cost reduction once the devices are mass produced. Also, for optical fiber communications, this kind of etalon could be widely used as a low-cost temperature-insensitive wavelength reference. Finally, in-line all-fiber tunable filters could eventually be made by coating the fiber ends with highly reflective films and modulating the cavity length using a driving device such as a piezo-electric transducer.

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