Optical comb filter generation in micro cavity employing Zinc Oxide based film

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Abstract. Optical comb filter generation was proposed and experimentally demonstrated by using Fabry-Perot interferometer in micro cavity. The change of length of Fabry-Perot interferometer modifies the interference pattern with the adjusted length is from 0 µm to 350 µm. The parameter of the generated comb such as free spectral range, extinction ratio, quality factor and finesse was recorded with and without Zinc Oxide based film (nano powder and nano particles). The stable comb filter was generated with a length of 100 µm for both Zinc Oxide-based film and 150 µm for the uncoated mirror. At the maximum length of 350 µm, Zinc Oxide nano particles film generates most stable optical comb filter with free spectral range, extinction ratio, quality factor and finesse of, 3 nm, 8 dB, 1298 and 2.5, respectively.

1. Introduction
The study on optical fiber can be traced back to early 1982 [1]. Optical fiber usually comes in two types; single-mode fiber (SMF) and multimode fiber (MMF). SMF was widely used for its ability to transmit a signal over a long distance. The combination of the two types of fiber was successfully demonstrated in generating a simple comb filter as reported by Wang et al. [2] and Zhao et al. [3], using a single mode-multimode-single mode fiber (SMS).

The fiber comb filter as the name implies acts as an optical signal sorter that helps to separate signals from different channels in proximity, thus aiding in reducing chances of crosstalk [4]. Comb filter generations have been reported by Zhou et al. [4] using a cavity consisted of only fibers. The research also made use of the multimode interference and Mach-Zender interferometer effects on the cavity. The generation of comb filter was also usually based on Bragg grating [5] which is becoming less attractive with the surfacing of interferometric cavities. These versatile cavities are higher in sensitivity and can be configured with different designs [6]. A micro cavity generating comb filters is no stranger in the optical sensor world and have been reported by a few in the past few years [6-7]. An optical comb filter was also reported using tapered fiber [8]. The principle is to make use of the interference effect in the ring resonator. This method is especially apparent in sensing applications and is usually approached by tapering the fiber through chemical etching process [9]. The use of fiber allows for ease of disposal and handling. However, the complex and delicate form of the fiber cavity has made the technique less popular than its newer counterparts. Another configuration based on polydimethylsiloxane (PDMS)
Fabry-Perot interferometer [6] was reported recently, with the micro cavity is between the SMF surrounded by PDMS.

This work, in particular, used the Fabry-Perot interferometer in the micro cavity to allow for length adjustment between the fiber tip and the mirror. The air gap is the common way to approach this technique, nevertheless, this work will demonstrate the effect of placing a thin film based on ZnO-PVA film (nano powder and nanoparticles) in between the fiber tip and the mirror and the resulting performance is discussed and compared to the ones with air gap micro cavity.

2. Methodology
The experimental setup of the micro cavity is as shown in figure 1. The cavity was pumped by a 1550 nm amplified spontaneous emission (ASE) light source through a 50:50 optical coupler. The microscope was used to observe and accurately adjust the distance between the fiber tip and the mirror. The reflected light by the mirror was measured using an optical spectrum analyzer (OSA) in the form of comb filters.

![Figure 1. Experimental setup of the micro cavity.](image)

3. Results and Discussions
From the air gap, ZnO nanopowder and ZnO micro cavities, three sets of comb filter were obtained as shown in figure 2. The comb filter with ZnO nanoparticles was observed to have a better and more constant spacing at around 200 μm with highest Q-factor of around 1945 while the other two micro cavities showed more amplitude modulations with unstable bandwidth separation.
The comb filter's performances with air gap, ZnO nanopowder, and ZnO nanoparticles were compared in terms of its free spectral range (FSR), extinction ratio (ER), Q-factor, and finesse. The distance between the fiber tip and the mirror was slowly increased to obtain the best distance with the most stable comb filter operation. The distance was increased from 0 to 350 μm with the comb filter started forming at around 100 μm. The relationship between the microcavity performances against the tip-mirror distance in terms of its FSR is illustrated in figure 3. The FSR was seen to decrease with the increasing distance applied. The decrease in FSR was more linear in air gap microcavity. This may be due to lower refraction occurring in the cavity without the ZnO based films.
The graph of the ER’s relation with regards to the tip-mirror distance is depicted in figure 4. At around 200 μm, all of the tests showed nearly similar value indicating that their minimum and maximum spectrum were in equal high at about 9 dB. ZnO nanoparticles showed higher ER of around 8 dB to 10 dB. 

The Q-factors of the micro cavities shows an increasing linear trend in figure 5. The Q-factor micro cavity with airgap increases throughout the distance while both of the ZnO films contributed to the slight decrease at 350 μm.
The finesse of the micro cavities for the three cases is also plotted against the distance as shown in figure 6. The narrow heaving resonance bandwidth of the cavities causes the wave pattern of the finesse graph [10]. Researchers usually seek for a moderately valued finesse in a comb filter to have a good balance between the stop and pass filter as higher finesse means a wider pass filter [11]. Hence, this particular parameter can be manipulated to get the desired filter effects.

At the fiber tip and mirror distance of 350 μm, the FSR was recorded at 3.4 nm for the air gap and 3 nm for both ZnO nanopowder and nanoparticles. The ER for the microcavity with ZnO nanoparticles recorded the highest at 8.8 nm. Higher ER is preferable in a sensor system to ease the process of detecting errors through attenuation effects [12]. The ratio of resonance-to-bandwidth of the operating wavelength
which defines the Q-factor of the comb filter was calculated at 1945.5, 1555.4, and 1298 for each of the microcavity components, respectively. The finesse of the microcavity with the airgap, ZnO nanopowder, and ZnO nanoparticles stayed within below 5 at 4.25, 3, and 2.5, respectively. The performance comparison is tabulated in table 1.

Table 1. Micro cavities performances comparison

| Micro cavity          | FSR (nm) | ER (dB) | FHWM (nm) | λ (nm) | Q-factor | Finesse |
|-----------------------|----------|---------|-----------|--------|----------|---------|
| Airgap                | 3.4      | 6.8     | 0.8       | 1556.4 | 1945.5   | 4.25    |
| ZnO nanopowder       | 3        | 2.32    | 1         | 1555.4 | 1555.4   | 3       |
| ZnO nanoparticles     | 3        | 8.8     | 1.2       | 1557.6 | 1298     | 2.5     |

4. Conclusion
The ZnO nanoparticles showed the best average performance in terms of comb filter generation and can seriously be considered as a pioneer in replacing micro-airgap cavity comb filter for sensor purposes. The micro cavity with ZnO nanoparticles generated a stable optical comb filter with free spectral range, extinction ratio, quality factor and finesse of, 3 nm, 8 dB, 1298 and 2.5, respectively.

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