Thermo-optical Tuning of Erbium-Doped Fiber Ring Laser

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Abstract: A thermo-optically tunable multimode interference fiber laser is demonstrated. The laser emission can be easily tuned trough the C-band by simply changing the temperature around the multimode fiber liquid cladding of the filter.
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1. Introduction.

The development of erbium doped fiber (EDF) lasers has experimented a significant grow due to their potential applications in numerous fields such as, spectroscopy, laser sensors, and wavelength division multiplexing (WDM) systems, among others [1]. Tunable filters are often used as the wavelength tuning components of the lasers, and the final tuning range depends on the tuning capability of the filter. Today numerous kinds of band-pass tunable filters are effectively employed in fiber laser systems, such as Fabry-Perot, fiber gratings, and side-polished fiber comb filters [2 - 4]. Multimode interference (MMI) devices have been widely investigated for different applications because they are very simple and inexpensive to fabricate, while providing a bandpass response that can be used as a filter. As a result, tunable fiber filters has been reported and successfully employed in a laser cavity [5]. Here, we present a wavelength tunable MMI-based fiber laser. The tuning operation of the MMI filter is realized by thermo-optic effects in the liquid cladding of a special multimode fiber (MMF). We inserted this thermo-optically tunable filter in a conventional fiber ring cavity laser by using EDF as gain medium, and we were able to demonstrate a tunability of 50 nm, covering beyond the full C-band, with a temperature increment as small as 40 Cº.

2. Principle of operation.

The key element of the proposed thermo-optically tunable MMI fiber laser is its tunable filter. The main fixture for maintaining the MMI filter is a metal channel filled with a particular refractive index (RI) liquid, which will act as fiber cladding, and placed directly over a hot-plate as shown in Fig. 1. For the MMI structure we use a specific section of MMF, which has a core diameter of 80 µm and air as its cladding, spliced between two single mode fibers (SMF) segments, which are the light input and output. In this way, based on the well known self-imaging effect, light coupled to the MMF through the SMF will produce self-images of the input field along the MMF. By cleaving the MMF at particular lengths, it is possible to choose the self-imaging distance which will provide the starting peak wavelength of the filter; this can be easily calculated by.

$$\lambda_0 = p\frac{n_{MMF} D_{MMF}^2}{L_{MMF}} \quad with\ p = 0, 1, 2, ... \tag{1}$$

where, λ_0 is the free space wavelength, n_{MMF}, D_{MMF} and L_{MMF} are the refractive index, diameter and length of the MMF respectively. For this particular laser application we choose the eighth (P = 8) self-image, since the spectral width response of MMI filter increase with the reduction of the MMF diameter. Therefore, a large self-image number will narrow the filter spectral width to provide significant wavelength discrimination and being able to work as a tunable filter. The band-pass filter response of the MMI filter at 18 ºC is displayed in the inset of the Fig. 2(a). The relative wavelength shift caused by the temperature variations can be expressed as [6],

$$\Delta\lambda = \lambda\left[(\alpha_1 + \xi_1)\Delta T - (1 + 2\nu + P_e)\varepsilon + \chi\xi_2\Delta T\right], \tag{2}$$

where λ and ΔT are the wavelength and temperature increment, respectively. The first and third part in the sum correspond to contribution of the change in the temperature on the MMF core and the cladding respectively, the second part correspond to an axial strain of the MMF due to the coefficient of thermal expansion (CTE). The constants α_1 and ξ_1 are respectively the CTE and thermo-optic coefficient (TOC). The constants ν, P_e and ε are respectively Poisson's ratio, strain-optic coefficient and axial strain of the MMF. Finally, χ and ξ_2 are a constant and TOC of the liquid cladding. As the temperature is increased the wavelength decreases because the TOC of the liquid cladding introduces a negative ξ_2 contribution. This is easily observed in Fig. 2(a) where the MMI spectrum is shifting to shorter wavelength as the temperature is increased.

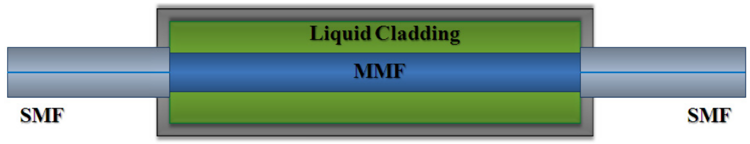

Fig. 1 Schematic of MMI Thermo-Optically tunable fiber filter.

3. Results and discussion.

As explained before, in order to obtain a higher sensitivity of the MMI device to temperature increments requires a smaller MMF diameter. In our experiments, we use a MMF without cladding know as no-Core fiber with a diameter of 125 µm. Therefore, we reduce the diameter by immersing the No-Core finer in buffered oxide (BOE) solution. The length of the MMI device is cleaved taking into account that as the diameter of the No-Core MMF is being reduced, the peak wavelength will shift to shorter wavelengths. The ring cavity was composed of 8 m of C-band EDF as the gain medium. The EDF was pumped by a 980 nm laser diode, operating at 200 mA, through a 980/1550 WDM coupler. The EDF output was launched to the MMI thermo-optically tunable filter input, and its output is connected to a 90/10 coupler. The laser spectral response is monitored through the 10% arm, using an optical spectrum analyzer, while the 90% arm was spliced to an optical isolator to have an unidirectional power flux. The output of the optical isolator was coupled to 1550 nm arm of the WDM, which closes the laser ring cavity.

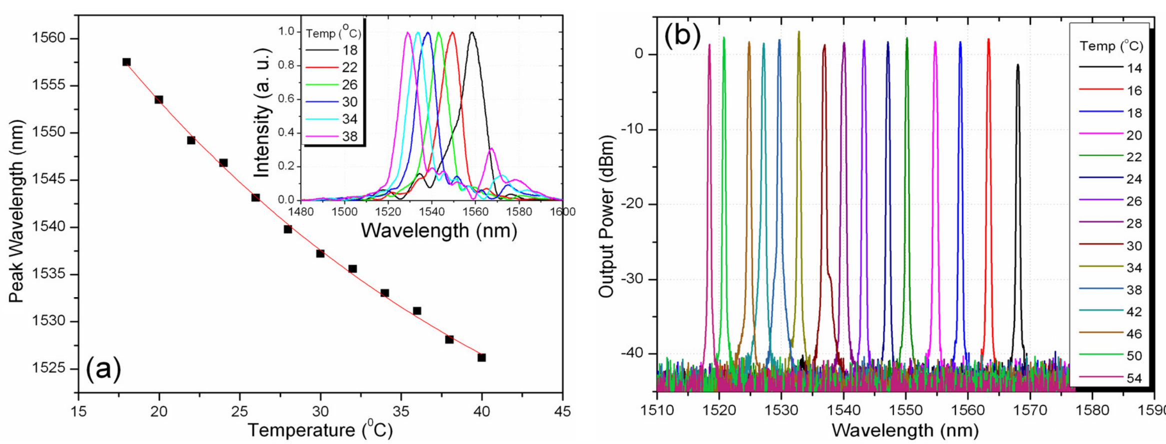

Fig. 2 (a) Wavelength response of the thermo-optically tunable filter as function of the applied temperature, (b) Superimposed laser spectral response when the MMI fiber filter is thermally tuned.

The MMI filter is designed to operate at longer wavelengths for low temperatures values. However, as the temperature increases the lasing output is tuned to shorter wavelengths. The superimposed spectral laser output as a function of the applied temperature is shown in Fig. 2(b). The laser wavelength was continuously tuned, with high stability, at least 50 nm when the temperature was varied from 14 to 54 °C with a spectral line-width of 0.4 nm. The signal to noise ratio was almost 45 dB and the optical output power was 1 mW. Our results demonstrate that using a liquid cladding with a large TOC provides a simple way to easily tune 50 nm with a very small change in ΔT.

4. Conclusions

We demonstrated a novel thermo-optically tunable MMI-based fiber laser with high wavelength stability and spectral line-width of 0.4 nm. The signal to noise ratio was almost 45 dB and the optical output power was at least 1 mW. The proposed scheme is very promising since it provides a compact structure that does not requires any moving mechanical part. Furthermore, we are able to tune the laser emission by using liquids with different RI values, thus achieving tuning over the full C-band with minimal temperature increment. The fabrication of this fiber laser is straightforward and with a minimum cost, which shows potential for several applications.

Acknowledgments

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