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Research Article

SPECIALTY FIBER GRATING DEVICES FOR REFRACTIVE INDEX SENSING AND PHOTONIC SWITCHING

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ABSTRACT
We demonstrate CO_2 laser written long period fiber gratings operating near turnaround point (TAP). We show that devices based on this principle provide highly sensitive measurement of ambient refractive index (RI) and novel functionality such as photonic switching. The experimental results show that the RI sensitivity of refractometer with an interaction length of 20 mm is up to 571nm/RIU in the range of 1.3288 – 1.427, which makes it an attractive platform for biochemical sensing. An increase in ambient refractive index of 0.44 has also been used in one of such devices for engineering a drastic change in spectral characteristics the device. The tailoring of dispersive conditions slightly away from TAP point for Photonic switching has not been reported by any group as per our knowledge.

Key Words: *LPG, Sensors, Refractive Index, Fiber Photonic Switching*

INTRODUCTION
Fiber-optic refractive index (RI) sensors have attracted much interest in recent years because of their broad applications in chemical and biological sensing due to their many advantages including corrosion resistance, immunity to electromagnetic interference, fast response time and real-time sensing. More importantly, Fiber Bragg gratings (FBGs) and long period gratings (LPGs) have been used for sensing various physical properties such as strain, radiation dose and refractive index.
For FBG sensors, the coupling occurs between the forward propagating core mode and backward – propagating core mode. As the core mode is not sensitive to surrounding refractive index, the fiber cladding of the FBG is often polished or etched to increase the evanescent field interaction with the surrounding material. However, the mechanical strength and durability of the sensor will be greatly reduced. A LPG couples the power from the forward propagating core mode to the co-propagating cladding modes. The cladding modes can be easily attenuated and this results in a series of attenuation bands centered at discreet wavelengths in the transmission spectrum of the grating. Each attenuation band corresponds to the coupling to a different cladding mode. A specific feature of LPGs is the sensitivity of the spectrum to the refractive index of ambient material i.e. the material that surrounds the cladding of the fiber (Patrick et al.,2002; Fan et al., 2011). The primary effect of change in the ambient index is the consequent change in the resonant wavelength.
We present long period fiber gratings operating near turn around point (TAP), fabricated by CO_2 laser based technique. The unique spectral characteristics of TAP gratings are a strong function of the dispersive conditions for the two modes that are being coupled and such a resonance can be accurately tailored. Operation near turn around point in long period fiber grating (LPG) provides extremely high sensitivity to external environmental parameters like temperature, strain and refractive index. It also provides the opportunity for development of novel devices for photonic applications (Wang et al., 2003). This added functionality is due to resonant coupling of higher order cladding modes and significant change in the slope of phase matching curve at TAP. The coupling of higher order cladding mode requires grating with relatively lower period (< 400 µm) whereas the fabrication of LPG with resonance exactly near TAP within 900-1700 nm band requires a very robust fiber and laser beam movement system with a precision better than 0.5 µm. We have conducted theoretical simulations and experimental studies on TAP-LPGs fabricated by CO_2 laser based index modulation method. We have identified specific grating periods and a method to operate near TAP for intended applications.

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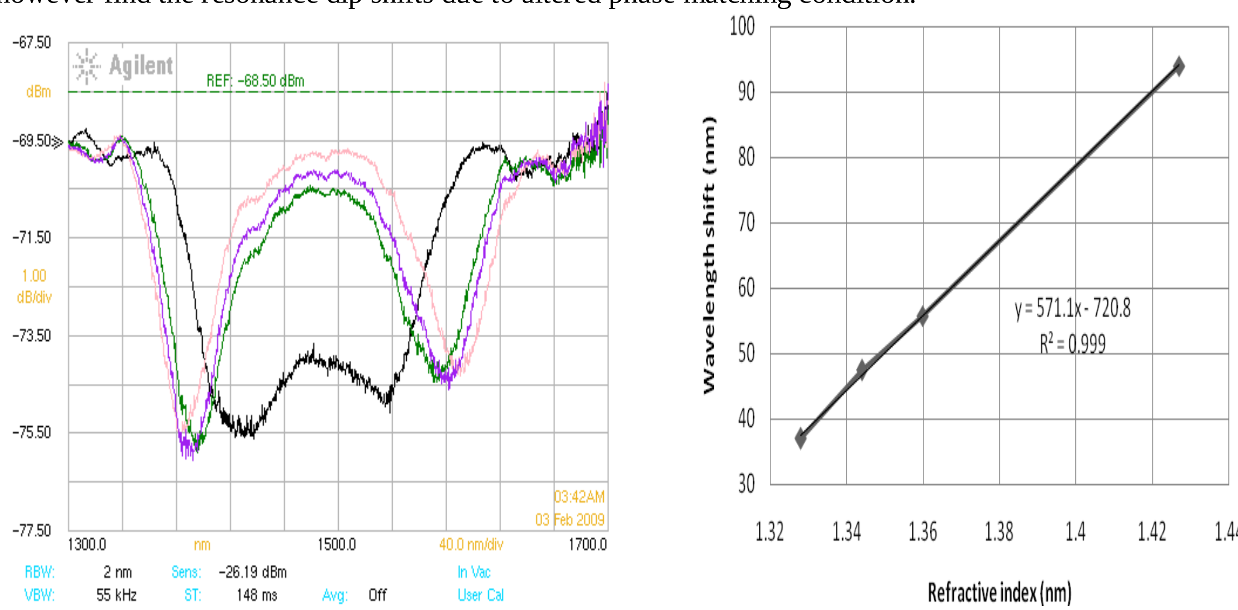
Two devices based on near TAP_LPG were designed, fabricated and characterized. The first device is so designed that the period is slightly smaller than the period required for exact TAP achievement This device has the signature of dual resonance dips and can be used for wavelength encoded highly sensitive refractive index sensing, Fig. 1(a). The second device has a period slightly higher than that required for exact TAP. When the ambient medium is air, none of core modes has a phase matching with any of the TAP cladding mode and the optical power is not coupled to the cladding mode. However, when the ambient medium refractive index is suitably changed, phase matching at TAP is achieved. This shows as resonance dips in transmission spectrum resembling Photonic Switch like operation, Fig 2.

RESULTS AND DISCUSSIONS

Fig. 1 (a) shows the grating transmission spectra of 206 µm grating period LPG under varying conditions of ambient refractive index from air(1)) to Nananol (1.427). Fig. 1(b) shows the wavelength shift observed in one of the dual resonances (1535 nm) with change in ambient RI. The linear fit of the curve results in sensitivity of up to 571nm/ RIU in the RI range of 1.328 to 1.427.
Fig. 2 shows the operation of Photonic switch due to change of ambient refractive index in a specialty LPG which was designed to operate slightly away from TAP point(210 µm grating period) when ambient medium is air. The green trace is the transmission spectrum of the grating showing the operation of such TAP-LPG. Due to phase mismatch, no broadband coupling is observed near TAP point (1350-1630 nm) while other lower order modes have normal coupling. The pink curve shows the transmission spectrum of the same grating device when ambient index is increased by 0.44. Upon change in the ambient index by a suitable value, phase matching for a TAP-cladding mode takes place resulting in formation of dual dip. There is thus drastic reduction of 10 dB in core mode power in 1400 nm band (3 dB width is approx. 25 nm) and 8 dB in 1570 nm band (3 dB width-25 nm). This type of wide band opening and closing due to ambient index change is like a two band photonic switch. It is also clear that the index change does not alter the coupling strength for other lower order cladding modes such remarkably. These modes do however find the resonance dip shifts due to altered phase matching condition.



(a) **(b)**

Figure 1. (a)LPG transmission spectra of 206 µm grating period LPG in B-Ge codoped fiber under varying conditions of ambient refractive index. (b) Wavelength shift observed due to change in ambient RI in the range 1.328-1.427. Linear fit of the data gives sensitivity of 571nm/RIU.

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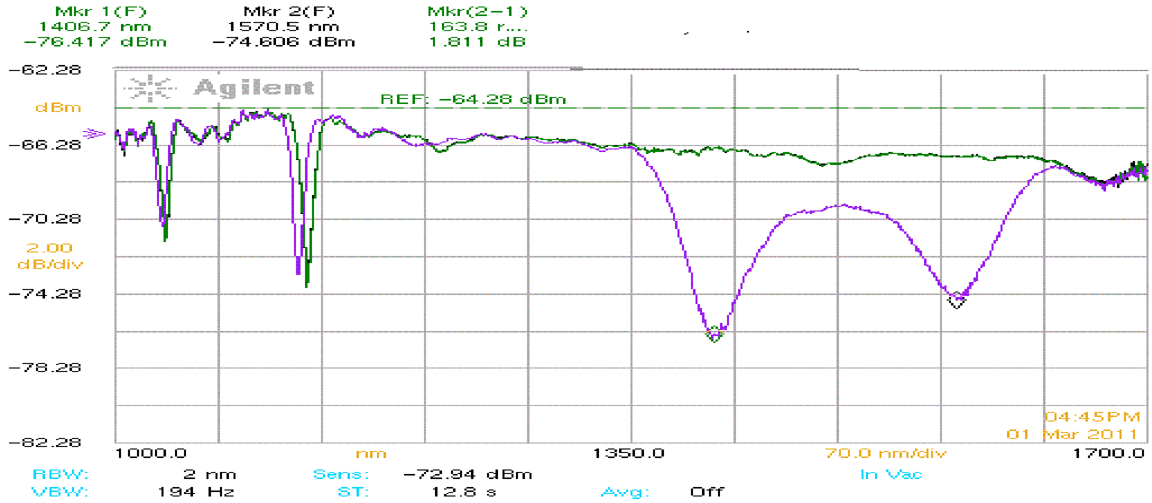

Figure 2. Photonic switching behaviour observed with an off TAP-LPG(210 µm grating period) inscribed in B-Ge codoped fiber. LPG transmission spectra for air (green trace) and Octanol (pink curve, RI= 1.4295) as external medium. Switching from near zero loss to 10 dB loss near 1400 nm and 1570 nm wavelngth bands due to RI change is quite noticable.

Conclusion

We have shown that specialty long period gratings can be used for sensing ambient refractive index with very high sensitivity. These gratings will find applications in bio-chemical analysis and for monitoring fuel adulteration. We have also shown that they can be used as photonic switches with dual pass band upon change of ambient refractive index. This has been demonstrated for the first time as per our knowledge. Since, the required change in RI is substantially high, this switch will not be very fast acting. However, the gratings can be precision designed so that a small change in RI could produce the switching effect.

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