1888
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Letters

In fibre amplitude modulation at GHz frequencies using elasto-optic effect in a fibre Bragg grating.

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We report in-fibre optical amplitude modulation via the elasto-optic effect up to 1 GHz using a fibre Bragg grating with coaxial acoustic transducer. The modulation showed resonances every 45 MHz. The peak wavelength shift resulting from the strain generated by the transducer was found to be ~30 pm.

Introduction

Fibre Bragg gratings have become an established part of the telecommunication industry. There has been extensive research into wavelength tuneable fibre Bragg gratings using thermal or strain effects [1-3], as dispersion compensators in fibre optic communication systems. The disadvantage of such devices is the slowness of the modulation process. Several groups had previously reported in-fibre phase modulators at up to hundreds of MHz using piezoelectric coatings such as ZnO deposited directly onto optical fibres (without gratings), [4-5], where peak phase shifts of the order of 1 radian have been obtained. Recently

Fox et al [6] have demonstrated wavelength tuneable fibre Bragg grating devices based on resistive and piezoelectric (ZnO) coatings deposited directly onto fibres. They show that in addition to the (slow) thermally induced wavelength shift (the major component) a modulated wavelength shift was obtained at a frequency of 15.26 MHz. They explained their finding on the basis of the axial strain component. The dominant effect of this would be a direct or "geometrical" modulation of the grating pitch in addition to the change of index via the strain-optic effect.

In this letter we report amplitude modulation up to 1 GHz using a fibre Bragg grating on which a film of ZnO has been deposited. At these frequencies, the fibre is highly stiff in the axial direction, only radial strains are important, and the optical properties are affected via the elasto-optic effect. The frequency and applied power responses are presented.

Experimental details

The device (shown in Fig. 1) consists of a ZnO thin film transducer deposited on a rotating fibre Bragg grating using RF reactive sputtering of a 99.999% Zn target in Ar/O_2 gases. The thickness of the ZnO film transducer is ~3 μm. A 3 mm Cr/Au top electrode defines the transducer length and matches the fibre Bragg grating length of 3mm.

The experimental set-up was as follows: A tuneable laser light source and photodetector were coupled to the two input ports of a 50:50 fibre directional coupler, the photodiode output was connected to an RF spectrum analyser. The grating modulator was spliced onto one of the output ports, while the other was angle cleaved to suppress reflection. The wavelength of the tuneable laser is adjusted so as to be approximately half-way up the grating reflection peak. Of the light reflected from the grating, 50% is incident on the photodetector (New focus-1611, bandwidth 1 GHz).

Results and discussion

The plot of amplitude modulation versus frequency is shown in Fig. 2. The applied RF power to the transducer is kept constant at 100 mW. The radial geometry of the transducer gives rise to a comb of acoustic resonances in the fibre, shown clearly over a frequency range of 0.05-1 GHz. The resonance peaks are separated by 45 MHz, corresponding to a fibre diameter of 125 μm. Electrical impedance measurements (not shown here) demonstrate that the transducer/fibre structure has strong resonances up to 2 GHz.

Fig. 3 shows the modulation power as a function of the square root of the driving power, measured at the 570 MHz resonance. At each applied power, the laser wavelength is adjusted to compensate for the wavelength shift induced by the heat generated by the transducer, a maximum shift of 140 pm is observed, equivalent to a temperature increase of ~14°C. The modulation power increases linearly as the square root of applied RF power (proportional to peak strain) up to ~250 mW, after which the increase becomes sub-linear, this saturation effect has been observed before with in-fibre ZnO phase modulators [4]. Saturation is attributed to the (initially reversible) degradation in the transducer efficiency due to heat generation, and has never been directly quantified before *in-situ*.

Provided the strain field, sinusoidal in time, is homogeneous over the length of the grating, the main effect on the reflection peak is to cause it to oscillate about its mean position thus modulating the reflected optical power. Fig. 3 also shows this peak wavelength shift as function of the RF power applied to the transducer, calculated from a knowledge of the slope of the reflection peak $dR/d\lambda$ at the operating point and the mean optical power reflected from the grating. A maximum wavelength modulation of ~30 pm is achieved. A wavelength modulation of 1.61 pm/mW$^{1/2}$ up to applied power of ~250 mW is shown. Using the calculated wavelength modulation values, we can simply estimate the corresponding change in the refractive index induced by the strain using the relation

$$\frac{\Delta n}{n} = \frac{\Delta\lambda}{\lambda} \qquad (1)$$

where n is the mode refractive index and λ is the Bragg wavelength. Equation (1) shows that a peak index modulation of $\sim 4\times 10^{-5}$ is achieved. This would be enough to produce ~0.8 radians of phase modulation if the same transducer was used as a simple fibre phase modulator of length 5 mm operating in the 1500nm region. One feature of figure 2 needs pointing out. In a phase modulator, as the acoustic wavelength is reduced, the width of the radial acoustic standing wave pattern approaches the fibre mode diameter, leading to phase cancellation and reduction of useful modulation above ~700 MHz [7]. In our amplitude modulator, we see clearly that modulation up to 1 GHz is obtained, although some of the peaks in the neighbourhood of 800 MHz are suppressed due to partial phase cancellation. It is the core diameter (i.e. the grating diameter) and not the mode diameter which is important here, which explains why operation of the amplitude modulator above 700 MHz is possible.

In conclusion we demonstrated for the first time amplitude modulation up to ~1 GHz by means of the elasto-optic effect using a ZnO thin film transducer deposited on fibre Bragg grating. Work is in progress to examine the effect above 1 GHz and to explore the possibilities offered by adjusting the homogeneity of the acoustic field in the axial direction.

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Fig. 1

N.K. Zayer, et.al.

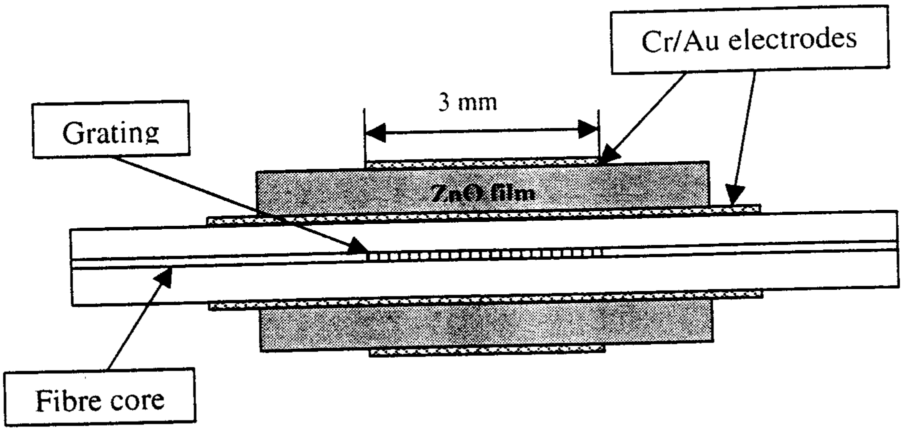

Fig. 2

N.K. Zayer, et. al.

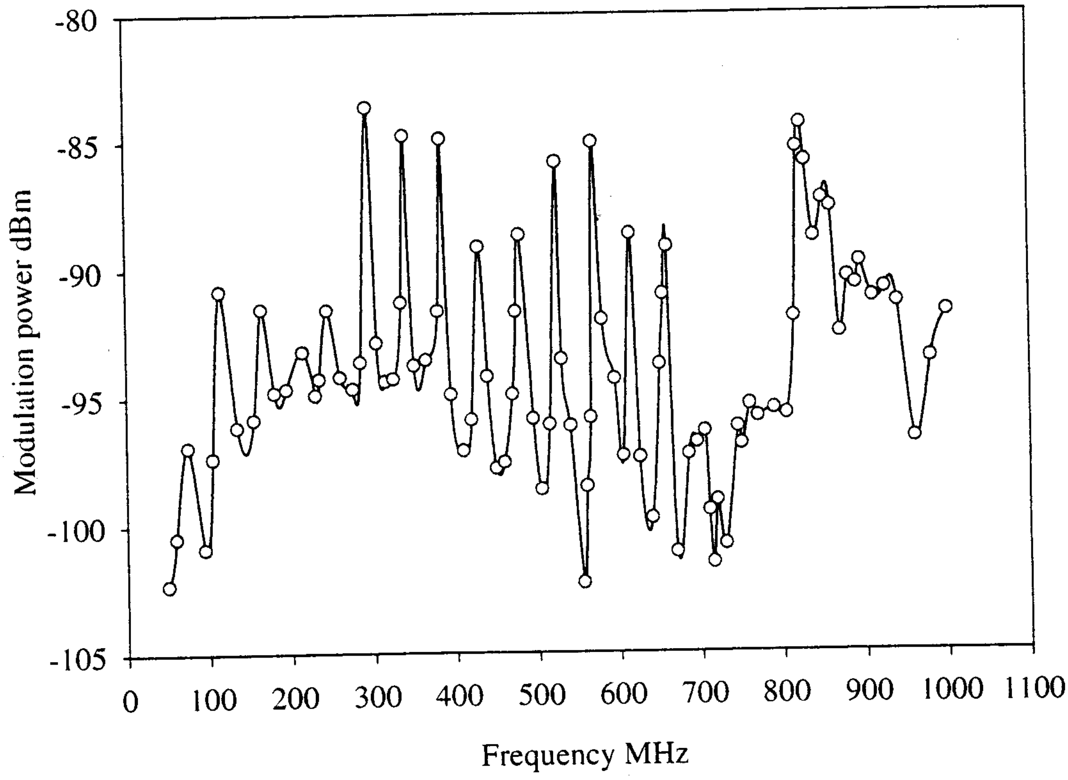

Fig. 3

N.K. Zayer, et. al.

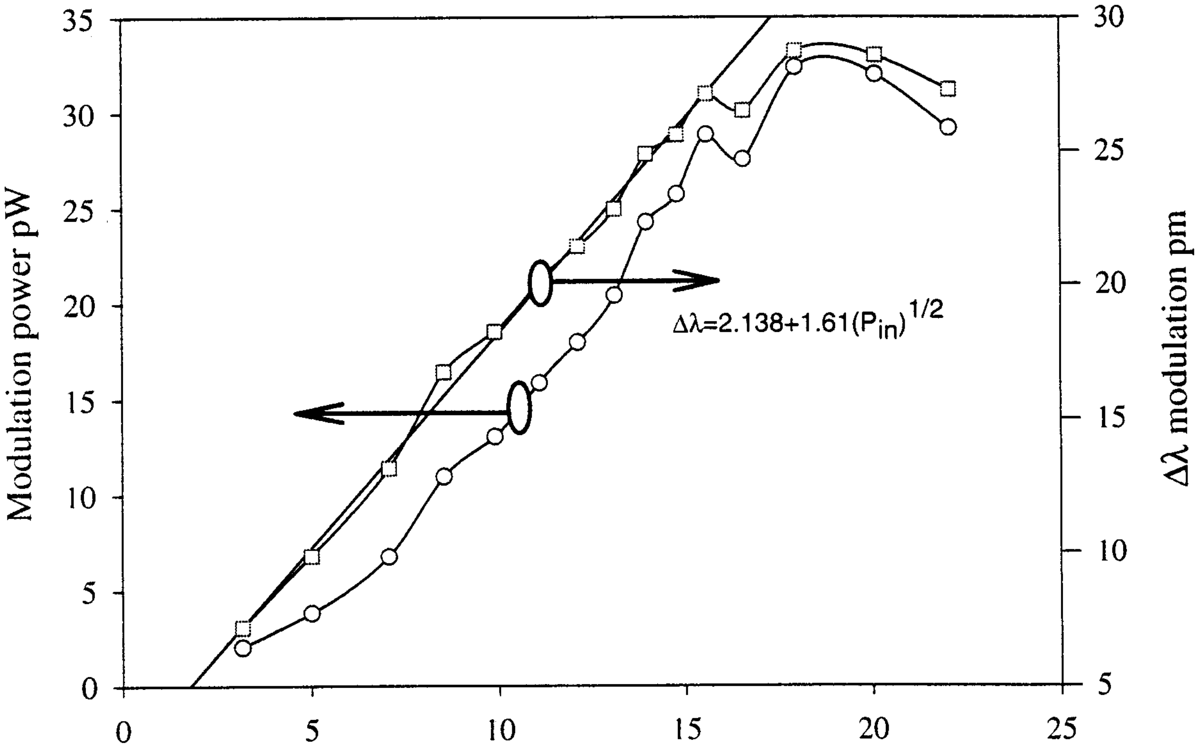

Figure captions

Fig.(1): Schematic diagram of the device structure.

Fig. (2): Amplitude modulation versus frequency. The applied power is kept constant at 100 mW.

Fig. (3): Amplitude modulation and calculated wavelength modulation as function of square root of the applied power. The resonance frequency is 570 MHz.