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AN ALL FIBRE ELECTRO-OPTIC KERR MODULATOR

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INTRODUCTION

Optical modulators play an important role in optical fibre communication as well as fibre-sensor systems. Fibre modulators have been realised by several techniques such as elasto-optic phase modulators using PZT[1,2] or PVF_2[3], acousto-optic frequency shifters [4,5] and acousto-optic amplitude modulators [6]. Here we report a totally new and novel concept, a Kerr-effect phase modulator based on a fibre containing a pair of built-in electrodes.

In spite of the very-low electro-optic Kerr effect present in glass, it is in principle possible to construct an electro-optic modulator provided that a sufficiently-high electric field can be maintained over a long length of material. In this way, the small electro-optic effect can be compensated by the long interaction length. A fibre provides a practical means whereby this can be achieved. Thus a pair of long, parallel metal electrodes on either side of a fibre forms the basis of an electro-optic fibre modulator. However, even in this configuration difficulty is experienced in maintaining high-voltage electrodes over long lengths without electrical breakdown. A novel solution which also provides a high electric-field in the fibre core region is to incorporate electrodes within the fibre as close to the core as possible. We report here a method whereby such fibres can be fabricated and preliminary results on their modulation performance.

THEORY

The birefringent phase shift (in radians) between the two orthogonally-polarised field components in a single-mode optical fibre produced by a transverse electric field is given by

$$\varphi = 2KE^2L\pi \qquad (1)$$

where K is the electro-optic Kerr coefficient

E is the applied electric field intensity

and L is the interaction length.

In general, the applied electric field E(t) consists of a dc term, E_o and an ac component of amplitude E_1, varying at the modulation frequency m. Hence,

$$E(t) = E_o+E_1\cos\omega_m t \qquad (2)$$

If $E_o = 0$, then (1) becomes

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$$\varphi(t) = KE_1{}^2(1+\cos 2\omega_m t)\pi L \qquad (3)$$

Thus, the modulated optical signal frequency is twice that of the applied electric field.

For $E_o >> E_1$, (1) can be written as

$$\varphi(t) \sim 2K(E_o{}^2+2E_oE_1\cos\omega_m t)\pi L \qquad (4)$$

In this case, the modulated optical signal has the same frequency as the applied electric field and is larger in amplitude.This configurationis therefore preferable, since a d.c. bias field is readily obtainable, whereas a high-frequency signal voltage drive is normally limited to tens of volts.

EXPERIMENT

To implement the 'internal-electrodes' concept, a fibre having two metal-filled holes disposed on either side of the core has been fabricated. Figure 1 shows the cross-section of the fibre. The separation of the metal electrodes is about 16.5 μm, a compromise distance which minimises fibre loss caused by optical field penetration into the metal while maintaining high electric field.

As a further advantage of the construction fibre exhibits birefringence ($B \sim 4 \times 10^{-5}$) as a consequence of thermal stress. Moreover, the birefringent axes are, automatically aligned with the direction of the applied electric-field. Thus the design provides both the means of applying a high electric field and ensures it is correctly orientated.

Indium/Gallium alloy was used for the electrodes. The liquid metal was pumped into the holes in lengths of fibre up to 30m at a pressure of a few atmospheres. Preliminary experiments have also shown the feasibility of directly drawing a preform incorporating a metal. The d.c. electrical resistance of each electrode was measured to be ~ 300 ohm/metre.

A 30m long fibre has been made and tested in various lengths, using the experimental arrangment shown in Fig.2. Driving signals were fed to the electrodes by means of a pair of very thin gold wires. Figures 3 and 4 show the waveforms of the modulated light signals, in the absence or presence of applied d.c. bias. As expected from equation (3) Fig.3 shows a modulation at twice the frequency of the applied voltage in the absence of d.c. bias. For a large d.c. bias, the double frequency term can be ignored (equation (4)), and the modulated signal has the same frequency as the driving signal[Fig 4]. Figure 5 shows the measured phase shifts verses applied voltages at a frequency of 2KHz for an interaction length of 30m. For an applied voltage of 67V.r.m.s. the phase shift between the two polarised modes of the fibre was measured to be ~ 0.15rads/m. The a.c. modulation increased to ~ 1.72rads/m when a d.c. voltage of 400V is applied to bias the a.c. driving voltage. The modulator frequency response is plotted in figure 5 where it can be seen that the 3dB bandwidth of the device is about 2 MHz for a fibre interaction length of ~1 m. At present the bandwith is limited by the large capacitance of the metal electrode structure. However, the electrodes represent an electrical transmission line and impedence matching of the line can be achieved, yielding large improvements in bandwidth. Lower resistance of the electrodes would also be an advantage and this can be obtained by the use of alternative metals. Further work is underway to optimise the device configuration to obtain a larger electric field within the core region while keeping the electrode resistance and capacitance as low as possible. A resonant drive circuit is also under construction to further reduce the drive voltage.

CONCLUSIONS

A novel Kerr-effect fibre modulator has been constructed using a fibre with integral metal electrodes. The feasibility of the approach has been shown and a $\pi/2$ drive voltage of 47Vrms obtained. This is an unprecedently low drive voltage for a Kerr-modulator based on amorphous material.

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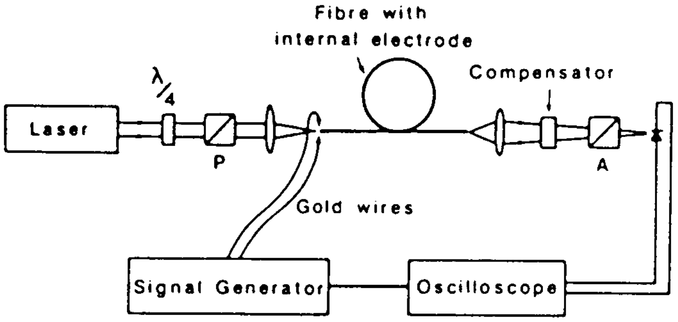

Figure 1. Experimental arrangement.

Fig. 2. Cross-section of a fibre with internal electrodes.

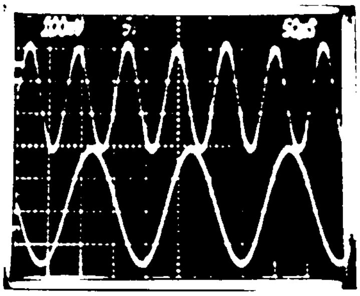

Fig. 3 Waveforms of the modulated signal (upper trace) and the a.c. driving signal (lower trace).

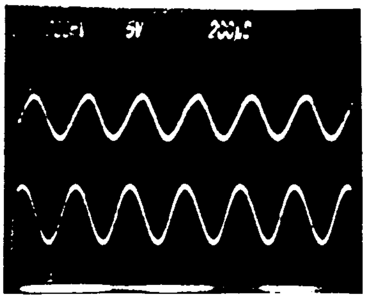

Fig. 4 Waveforms of the modulated signal (upper trace and the a.c. driving signal with d.c. bias (lower trace).

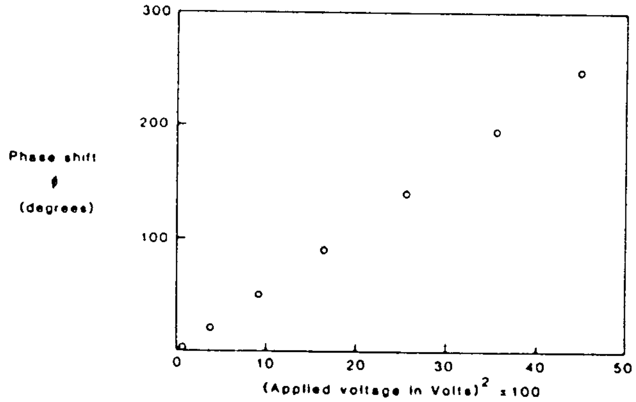

Fig. 5. Birefringent phase shift versus (applied voltage)^2 with an interaction length of 30m.

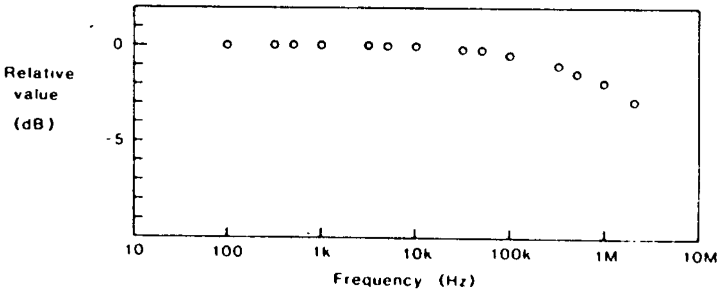

Fig. 6. Frequency response for the device with an interaction length of 1m.