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Liquid crystal materials' refractive index matched to silica

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A liquid crystal eutectic is reported that has refractive indices matched to silica at 25°C and 1·3 μm with the n_0 below that of silica and n_e above. It is demonstrated that the refractive indices of the eutectic allow a polarization filter, operating at telecommunications wavelengths, to be made on a silica-fibre based half-coupler block.

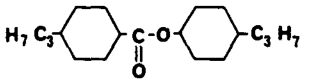
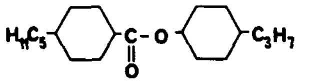
There have been a number of reports recently on the use of liquid crystals to make active and passive devices as waveguide overlays [1–3]. In order to use liquid crystals in devices based on standard silica fibres, rather than on special high-index fibres [3], the ordinary refractive index of the liquid crystal must be below that of silica at typical operational temperatures of 25°C. This is the first report of a liquid crystal eutectic which satisfied the operational criteria for a simple polarization filter operating at 25°C and 1·3 μm.

Two routes to low refractive index liquid crystals for silica-based devices were identified: firstly, cyclohexylcyclohexanoate derivatives, and secondly, the cyclohexane analogues of the cyanbiphenyls. The Merck material ZLI 1695 probably represents the best that can be achieved by the second approach. Thus the first group of materials was chosen; no data were available on their refractive indices. Several materials of this general family are commercially available, but only the mixture of OS-33 and OS-53 (Merck) formed a suitable eutectic. The structure, phase transition temperatures, birefringence and dielectric anisotropy of these materials are given in the table.

The phase behaviour of various mixtures of these materials was studied by observing the phase changes of a 125 μm thick sample under a polarizing microscope, whilst heating the sample in a Linkam hot stage at 0·5°C/min. The ordinary refractive index was measured using an Interphako interference microscope. The optical path length through a homeotropically aligned sample was compared with that of an identical thickness of silica. The interference pattern observed when the image of the liquid crystal is sheared onto that of the silica allows the difference in the refractive index to be calculated. Since it was the direct comparison with silica that was desired this technique was particularly useful. The indices were determined at 550 nm and the temperature dependence of the liquid crystals' indices against those of silica were measured.

Liquid crystals and silica have different wavelength dependences of their refractive indices, hence the transmission of the liquid crystal on a half-coupler block [4] was examined for both input polarizations in the region of 1·0–1·8 μm. When the effective modal index of the guide is greater than that of the liquid crystal overlayer the coupler

Liquid crystal properties.

Numbers	Compound	S_A–N	N–I	Δn	$\Delta\varepsilon$
OS-33		23°C	34°C	0·04	−0·3
OS-53		29°C	51°C	0·05	−1·5

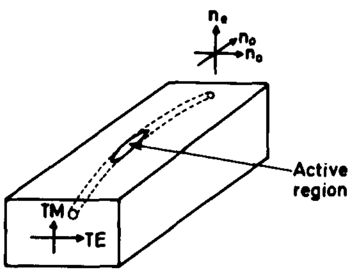


Figure 1. Schematic of half-coupler showing the polished, exposed fibre core (active region). Polarization directions (TE and TM) and liquid crystal refractive index axis.

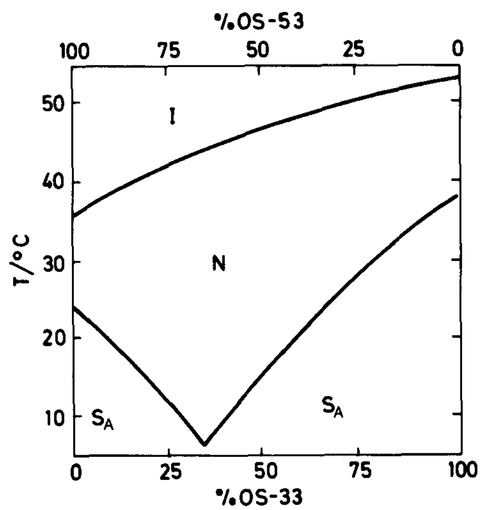


Figure 2. Phase diagram for mixtures of OS-33 and OS-53.

transmits. Otherwise the light is stripped from the guide. The liquid crystal was aligned homeotropically on the coupler block using etheric phosphatidyl choline. By suitable choice of orientation of the polarized light input, it was possible to observe the effects of both index directions on the propagation through the block (see figure 1).

An initial experiment showed that OS-33 had an ordinary refractive index similar to that of silica at 25°C but a nematic range of only 23–34°C. A eutectic was thus developed with the most suitable derivative, namely OS-53, which shows a wide-range high-temperature nematic phase. The phase transitions of the mixtures are shown in figure 2. The 65 : 35 eutectic was used for all subsequent experiments. The eutectic has

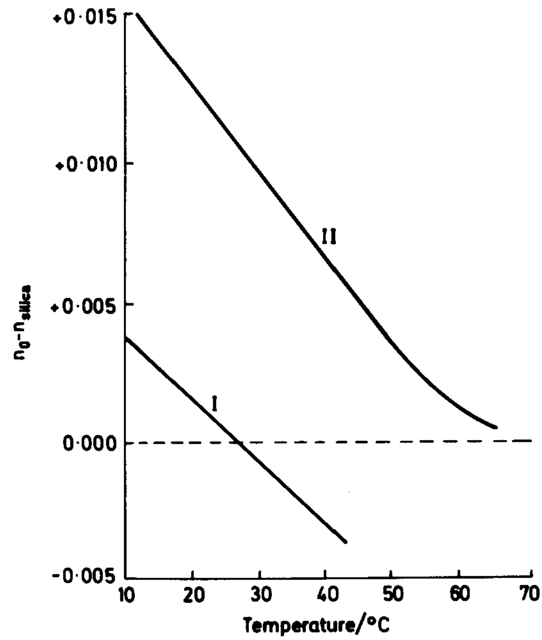


Figure 3. Refractive index–temperature data for (I) OS-33/OS-53, 550 nm, and (II) ZLI 1695, 589 nm. The dotted line shows the matching-to-silica condition.

a phase range of 7–42°C and a dielectric anisotropy of about −0·7. The birefringence is about 0·05. Figure 3 shows the refractive index against temperature plot for the eutectic as determined on the Interphako against a 100 μm silica coverslip. The figures for the lowest commercially available mixture, ZLI 1695, are given for comparison (Merck). Note that the ester is measured at 550 nm, so that the direct comparison to ZLI 1695 and silica (1·458) which were measured at 589 nm would require the subtraction of about 0·001 from the values given for the OS-33/OS-53 mixture to correct for the difference in the dispersion of quartz and alicyclic compounds in the visible spectrum.

These results indicate that, with the normal dispersion difference between silica and saturated hydrocarbons, the ordinary index should be low enough at 25°C to be used as an overlay on a half-coupler block. Experiments were thus carried out using a homeotropic alignment of a 125 μm thick liquid crystal film sandwiched between the coupler and a glass coverslip. Figure 4 shows the transmission characteristics of a typical cell agent wavelength. Two polarizations are shown, labelled as if the plane of the coupler block were a planar waveguide. Inspection of figure 1, which shows the director axis, demonstrates that, with the electric field in the plane (TE mode), the light accesses the ordinary refractive index of the liquid crystal and is transmitted. When a TM mode is propagated the extraordinary index is seen and most of the light is lost, probably via scattering and radiation modes. This structure is acting as a simple polarization filter. Notice that if a homogeneous alignment were used the selected polarizations could be reversed. At 32°C the ordinary index is lowered sufficiently to permit transmission at 1·55 μm.

The results clearly indicate that the liquid crystal reported can be used to control the transmission characteristics of standard silica components at 1·3 μm. It has a

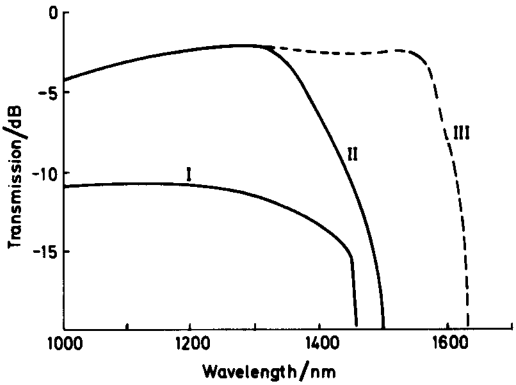


Figure 4. Transmission characteristics of a half-coupler block overlaid with a homeotropic liquid crystal layer. (I) TM mode at 25°C and 32°C, (II) TE mode at 25°C, (III) TE mode at 32°C.

reasonably wide nematic range of 7–42°C. The development of this eutectic should enable fabrication of various forms of switch [4] usable at operational wavelengths and temperatures.

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