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The effect of phase transitions on the response times of ferroelectric liquid crystal devices

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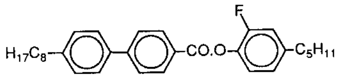
The response times of ferroelectric liquid crystal devices are of great importance, and are known to be related to various physical properties of the chiral smectic C* phase, such as the spontaneous polarization, the cone angle and the rotational viscosity. We report measurements of the effect of the smectic phase transitions on the response times and show that these are influenced by the smectic C* to smectic A transition temperature.

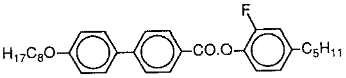
1. Introduction

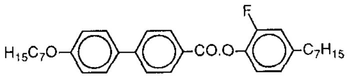
The response times τ of ferroelectric electro-optic liquid crystal devices [1] are of great importance and are known to depend on several factors; these include the spontaneous polarization P_s, the cone angle θ, and the rotational viscosity η. The response times can be made faster by decreasing η and θ, as well as by increasing either P_s or the applied electric field E. However, we may also expect the elastic constants to play an important role in determining the response times, and that these in turn should be related to the reduced temperature below the smectic phase-transition temperatures. We have therefore studied the response times of a series of very similar mixtures in which the only significant variables are the smectic phase-transition temperatures.

2. Experimental

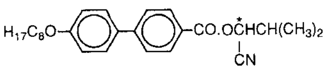
The ferroelectric mixtures used in the study were based on combinations of the MBF ester [2] host materials







together with 2·5 per cent of one of the recently announced transverse cyano chiral dopants [3]



This combination of materials represents a useful and versatile system [4], combining a wide smectic C* range with a facility to adjust the temperature range of the smectic A phase.

The experimental test cells for the various measurements all used rubbed polyimide alignment coatings. The cone angle was determined from observations of the two extinction positions induced in a 2 μm cell by the application of a 50 Hz, 5 V R.M.S. square-wave voltage. Cells of 6 μm thickness were used for the determination of P_s using a conventional Diamant Bridge, and also for η by measuring the switching current with a balanced resistance bridge [5] with a 30 Hz, 10 V R.M.S. square-wave voltage, using the method of Kimura *et al.* [6]. The rotational viscosity is related to the half-width of the switching-current peak τ_w by [6]

$$\eta = 0{\cdot}568\tau_w P_s E.$$

The response times were measured in 1·7 μm cells. A 20 V peak monopolar voltage pulse, with a duty cyle of 100 : 1, was applied and the pulse width decreased until the switching became incomplete. The response time was taken as the minimum pulse width for clean, or total, switching to occur. A high quality of alignment is necessary for the accurate measurement of response times, and this was achieved by using the technique described by Bradshaw *et al.* [7]; this combines the phase sequence

$$\mathrm{I\text{-}N^*\text{-}S_A\text{-}S_C^*}$$

with an N* pitch P that is sufficiently long that $P \geqslant 4d$, where d is the thickness of the liquid-crystal layer. The transverse cyano chiral dopant described previously is particularly useful since it produces a long N* pitch, and compensation [7] of the mixtures was not necessary.

3. Mixtures with variable smectic C* to smectic A transitions

A series of mixtures with smectic C* to smectic A transition temperatures covering approximately the temperature range 60–100°C. The phase-transition temperatures of this series of mixtures are shown in figure 1. The S_C–S_A transition temperature was varied by adding a small amount of a phenyl benzoate ester to the final mixture. This ester reduces the width of the S_A phase by lowering both the S_C^* to S_A and the S_A to N* transition temperatures until the S_A phase is completely eliminated and there is a direct S_C^* to N* transition. There is the added advantage that increasing this ester component also reduces the undesirable S_B phase present at low temperatures in some of the mixtures.

The physical properties of the mixtures relevant to response times were measured at the same temperature, 30°C, and the results are shown in figures 2–4. The spontaneous polarisation P_s (see figure 2) shows an approximately linear increase from 8 to 13 nC cm^{-2} as the S_C^* to S_A transition temperature increases from 60°C to 100°C; however, rather surprisingly, the cone angle (see figure 3) shows a small increase of only 14 per cent for the same change in the S_C^* to S_A transition temperature. The rotational viscosity (see figure 4) is virtually independent of the S_C^* to S_A transition temperature; this might be expected from the relatively minor changes made in the composition of the mixtures.

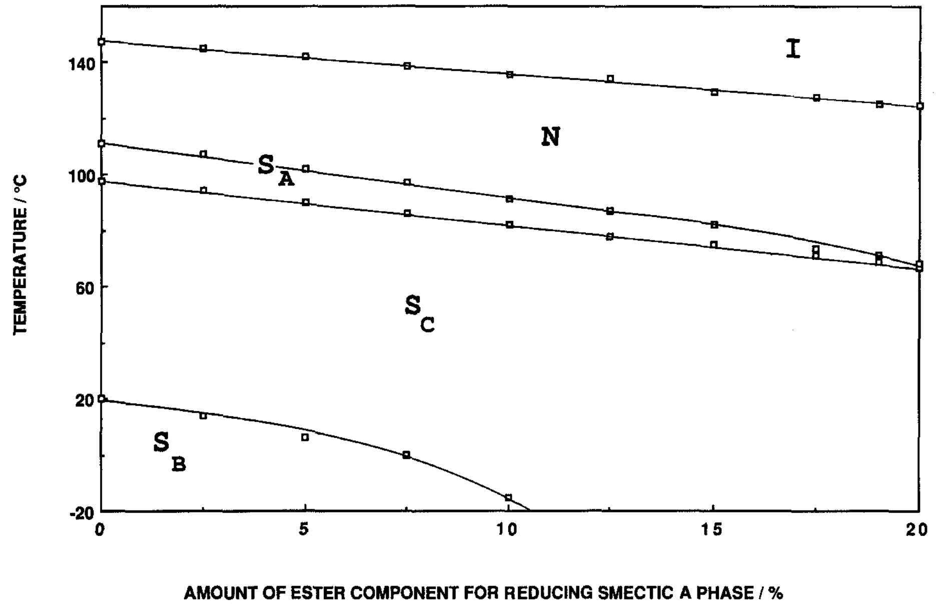


Figure 1. Phase-transition temperatures of mixtures containing different amounts of an ester component that reduces the width of the S_A phase.

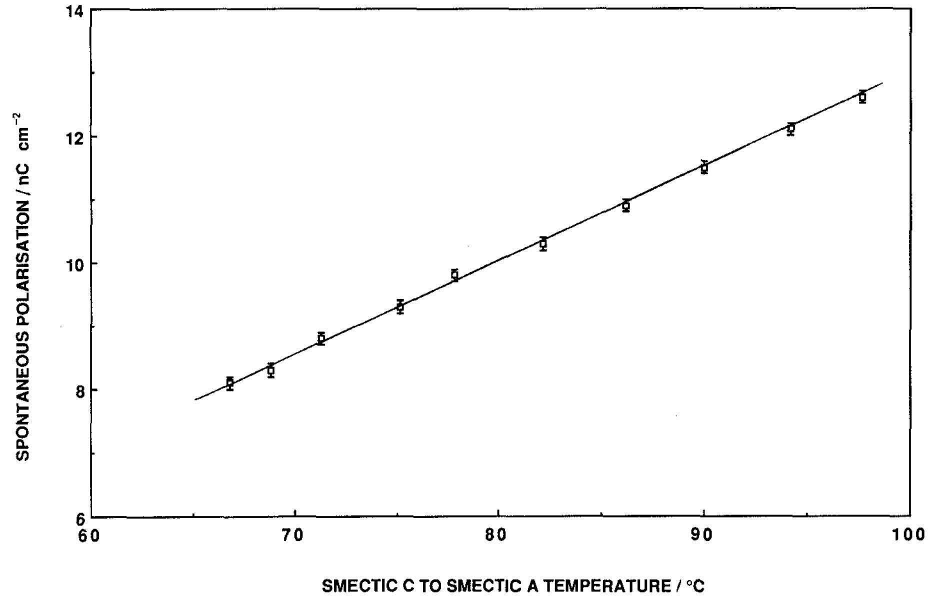


Figure 2. Dependence of P_s on the S_C^* to S_A transition temperature of the mixtures in figure 1.

4. Response times and discussion

The response times τ of the mixtures, measured using the method described previously, are shown in figure 5. Clearly they exhibit a strong correlation with the S_C^* to S_A transition temperatures, with almost a factor of three decrease in the response times as the S_C^* to S_A transition temperature is reduced from 100°C to 60°C. This

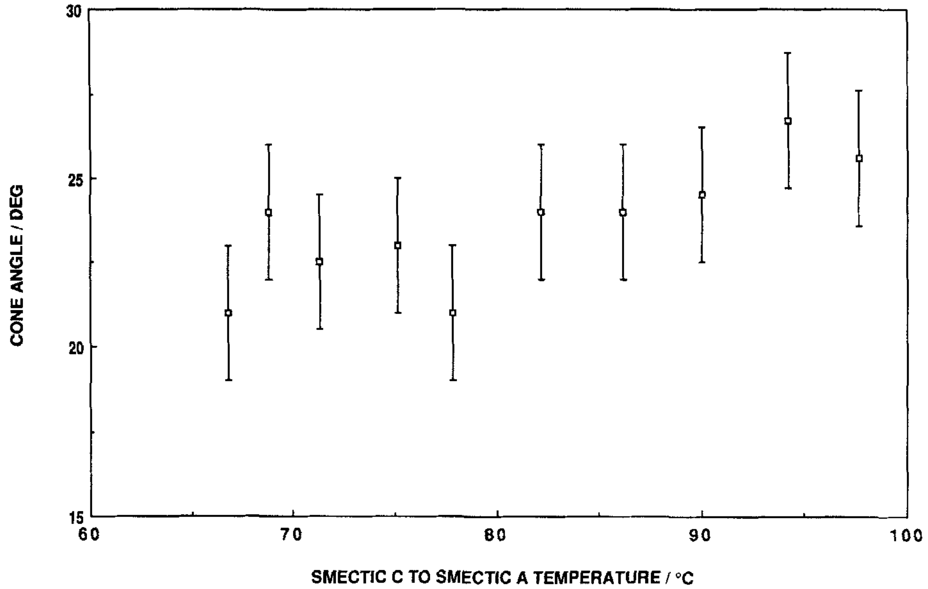


Figure 3. Dependence of θ on the S_C^* to S_A transition temperature of the mixtures in figure 1.

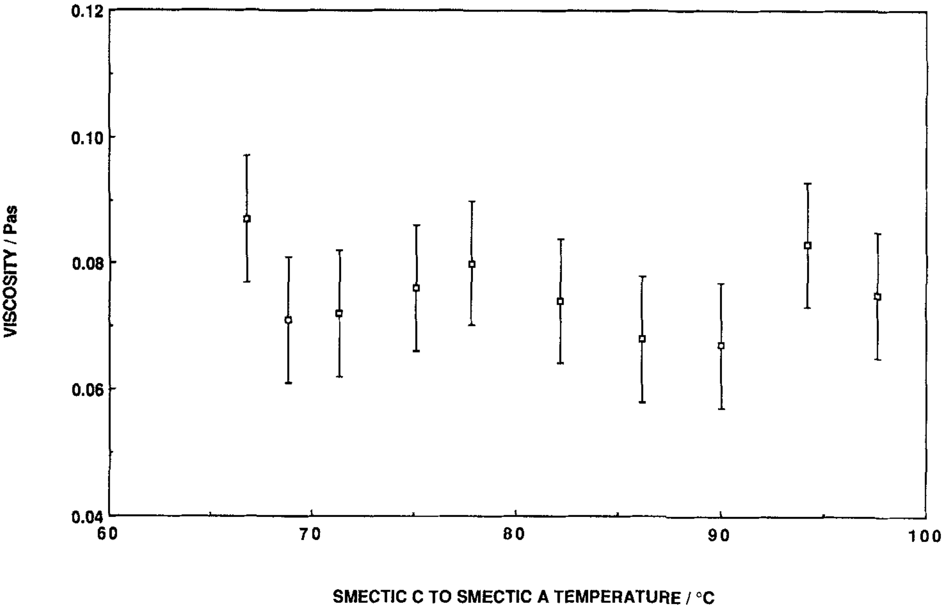


Figure 4. Dependence of η on the S_C^* to S_A transition temperature of the mixtures in figure 1.

occurs despite a reduction in P_s (see figure 2), which would, by itself, actually slow down the device rather than speed it up. The response times in figure 5 suggest that the physical properties we have measured (P_s, θ and η) cannot be the only factors determining the response times of ferroelectric devices.

The mixtures with the highest S_C^* to S_A transition temperatures exhibit a smectic B phase at lower temperatures (see figure 1), and the influence of this S_B phase on the response times was examined by measuring the change of response time as the

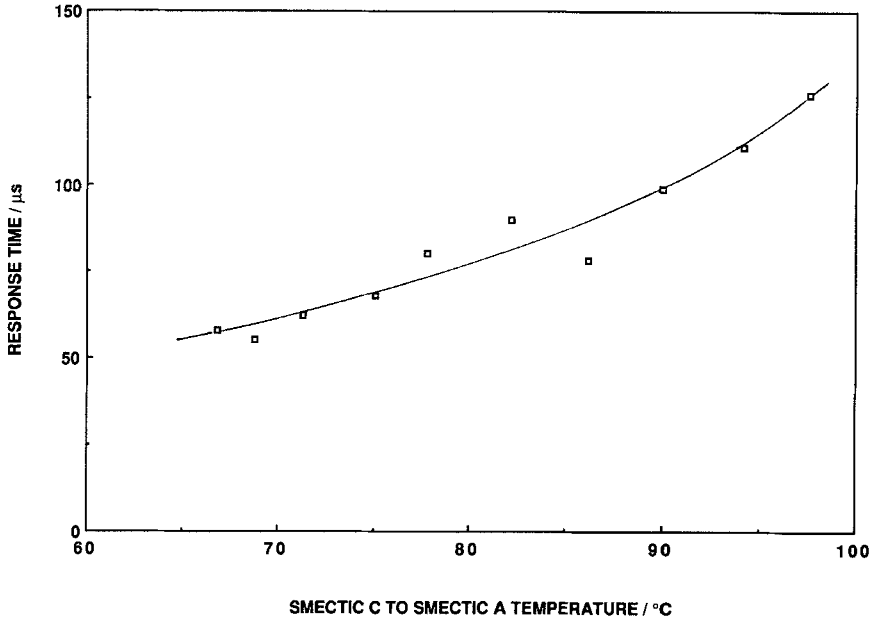


Figure 5. Dependence of τ on the S_C^* to S_A transition temperatures of the mixtures in figure 1.

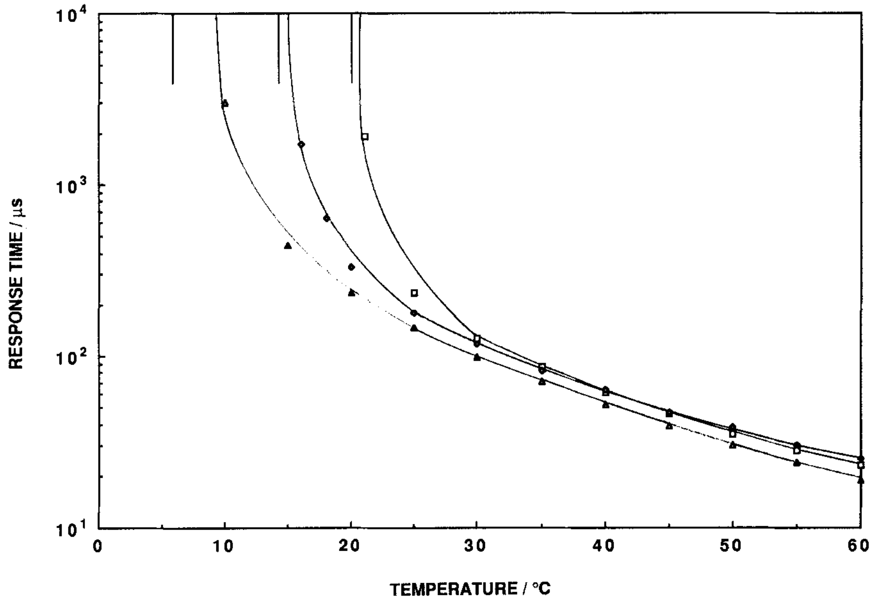


Figure 6. Temperature dependence of τ just above the S_B phase of the first three mixtures in figure 1.

temperature was reduced towards the S_B phase. The results in figure 6 show that the proximity of the S_B phase does indeed slow down the switching process in the S_C^* phase, but that this effect is only present to within approximately 20°C of the S_B phase. Therefore, with the possible exception of the two mixtures with the highest S_C^* to S_A transition temperatures, response times measured at 30°C are not influenced by the presence of the S_B phase at lower temperatures.

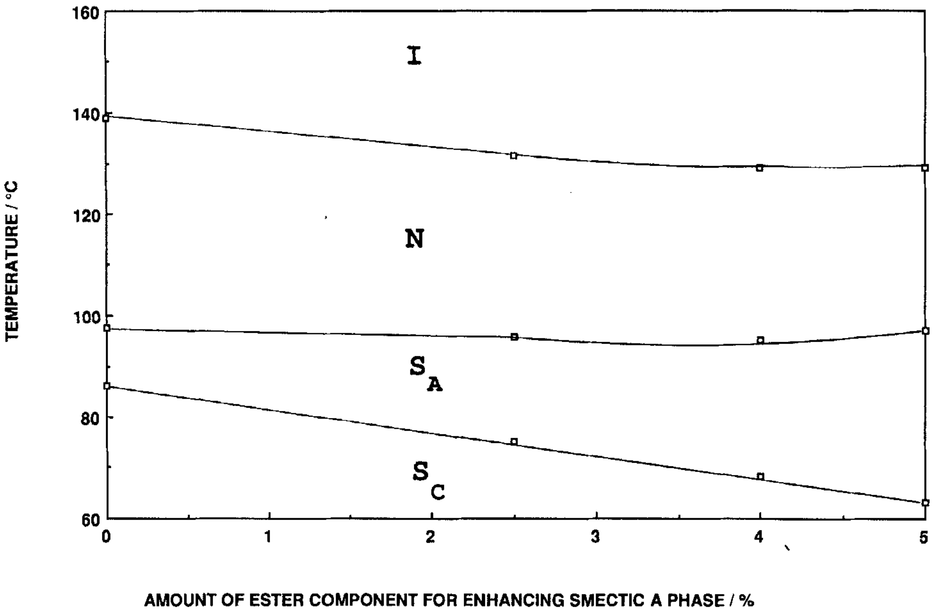


Figure 7. Phase-transition temperatures of mixtures containing different amounts of an ester component that enhances the width of the S_A phase.

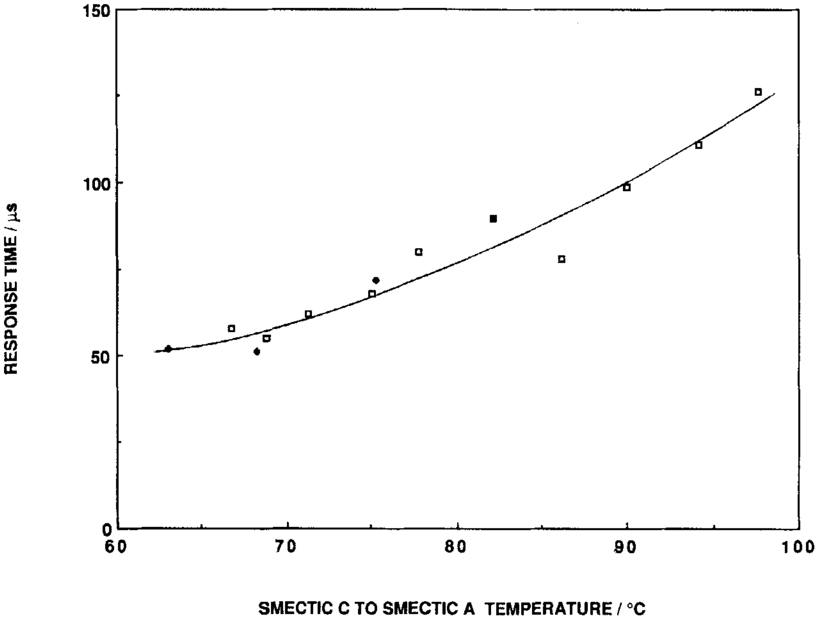


Figure 8. Dependence of τ on the S_C^* to S_A transition temperatures of the mixtures in figures 1 and 7.

The possible importance of the S_A to N* transition temperature on the response times was determined using a second set of mixtures with varying S_C^* to S_A transition temperatures but with a constant S_A to N* transition temperature (see figure 7). The response times of both sets of mixtures are shown in figure 8, and they clearly correlate well with the S_C^* to S_A transition tempratures, but not at all with the S_A to N* transition temperatures.

The variation of response times illustrated by the results in figure 5 is surprising, and some factor other than the physical properties we have measured (P_s, θ and η) must also be influencing the response times. The correlation with the S_C^* to S_A transition temperatures suggest that other physical properties related to this phase-transition temperature, such as order parameters or elastic constants, must also be important. However, measurements of these parameters do not exist for ferroelectric S_C^* materials, and, in many cases, the parameters themselves are not yet adequately defined in this phase.

5. Conclusions

We have shown that the response time of a ferroelectric mixture is dependent on the S_C* to S_A transition temperature. Decreasing this transition temperature yields a ferroelectric mixture with a faster response time, despite the accompanying decrease in P_s. We have also shown that the response times of these ferroelectric mixtures are unaffected by the S_A to N* transition temperature. These results are unexpected, and suggest that physical properties related to the magnitude of the S_C^* to S_A transition temperature are important in determining the response times of ferroelectric mixtures.

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