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Liquid crystals for display applications

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Active Matrix (AM) LCDs and STN LCDs are the leading display technologies for portable applications such as notebook computers. Recently, new LCD device configurations and new LCD operation modes have been introduced. The existing technologies and the new LCD operation modes require improved liquid crystal materials. The history of liquid crystals for display applications and recent progress in new liquid crystal structures is presented.

1. Introduction

In the last 10 years the LCD market has shown a significant growth starting from simple TN applications including watches and calculators and leading on to displays with high information content such as in notebook computers. In order to discuss trends in LC materials it is important to summarize the display market trend in general and the LCD market trend in particular.

In the overall display market, flat panel display technologies still have a smaller market share than the conventional CRT, but within the next five years it is expected that, also for large volume applications like desktop computers and televisions, flat displays will be utilized. Furthermore, the trend to mobile information processing and mobile communication will continue and cellular phones, e-mail and the Internet will become more popular. Therefore, the flat panel display market will continue to grow and since 1995 the expectation has been that not only LCDs but also Plasma Displays (PDPs) will be the most promising technologies. Especially for large size (40 inch) TV application, several Japanese companies have announced the market introduction of PDPs for 1998.

In the LCD market we can distinguish displays with high information content, such as portable computers, word processors, small TVs, camcorders and PDAs, and displays with low information content, e.g. watches, calculators, cellular phones and automotive applications [1]. The high information content LCD market will have the largest growth rates. New applications for LCDs will be in desktop PCs and work stations, in large size direct view TVs, in projection TVs, in PDAs with reflective colour displays and in car navigation systems. However, the market for low information content LCDs will remain important, and as an example, the number of cellular phones is expected to double to 100 million in 1999. Important applications for LCDs of different size and resolution are summarized in figure 1, together with some trends from present to future technologies.

Advanced LC materials had to be developed in order to fulfil the requirements of high resolution and large size LCDs. For simple calculator and watch displays, common use (CU) TN mixtures based on cyanobiphenyls are used, the materials which were invented by George Gray more than 20 years ago [2, 3]. Improved temperature range in broad range (BR) TN mixtures and improved viewing angle in VIP TN mixtures using phenylcyclohexanes [4, 5] followed 15 years ago, e.g. for automotive applications. Displays with higher contrast or higher resolution were then introduced such as Guest Host displays, High Mux TN displays or FLC displays, and another important class of materials for such technologies is represented by the phenylpyrimidines. The introduction of STN displays required materials with large dielectric anisotropy, e.g. cyano esters with lateral fluoro substitution [6], as well as materials with low rotational viscosity and a large elastic constant ratio K_3/K_1 which can be realized in alkenyl systems [7, 8]. And finally, TFT displays require LC materials with high stability like fluorinated LCs [9, 10]. Important LC materials for several LCD technologies are shown in figure 2.

2. LCDs: applications and technologies

2.1. *Notebook PC*

The notebook PC is the most important application for large size LCDs. In 1995 around 10 million LCDs were produced for this application and it is expected that this number will double by 2000. This significant increase comes from multimedia and Internet applications, but the display performance has to be improved.

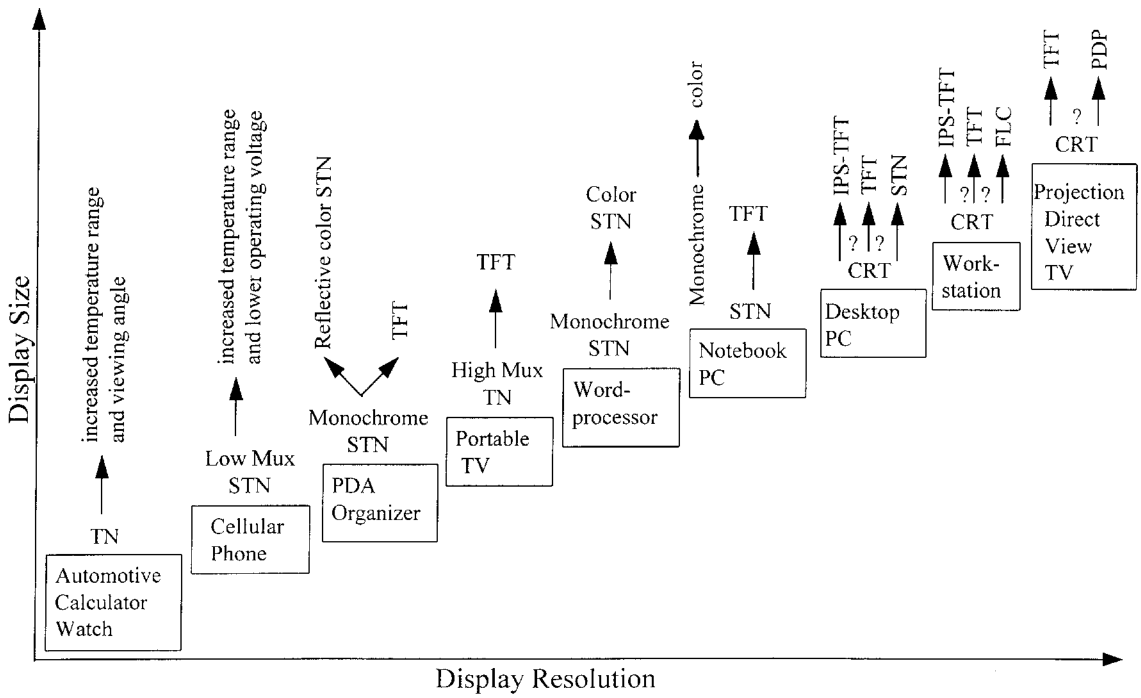

Figure 1. LC display market: past, present and future.

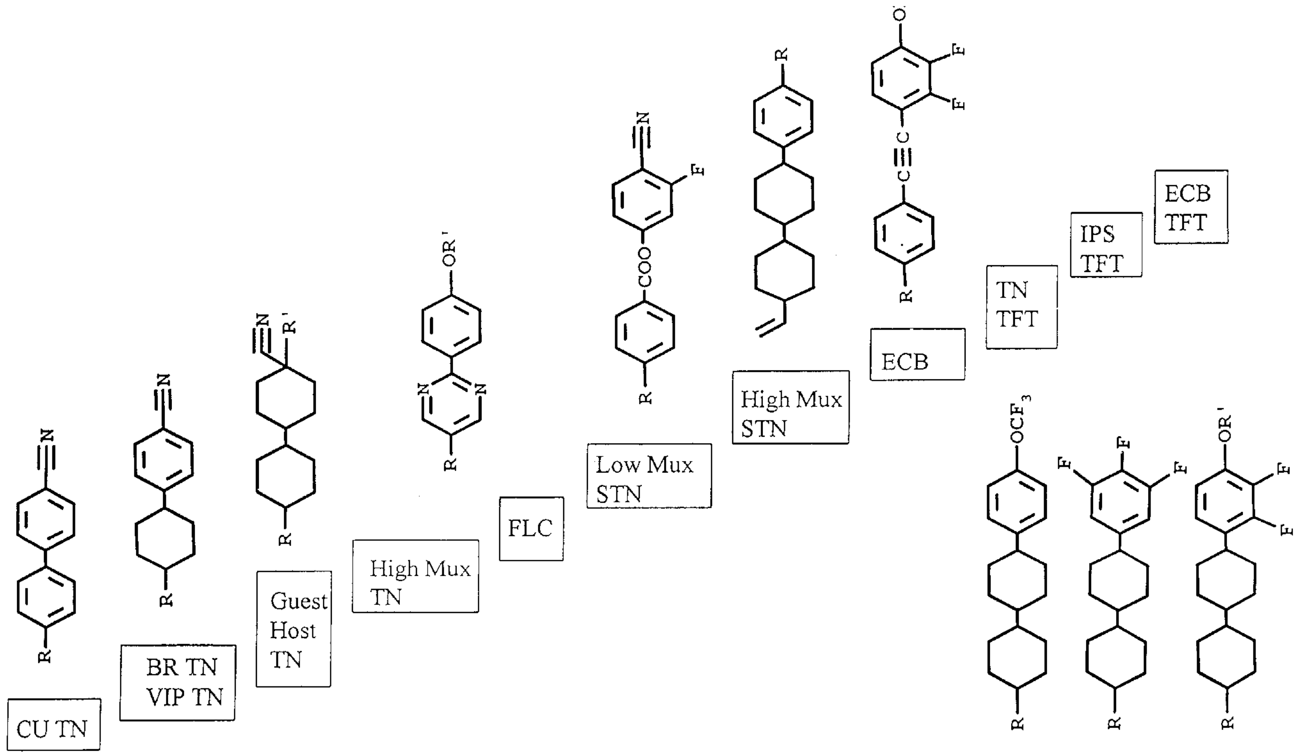

Figure 2. LC materials: past and present.

Larger size (10·4→12·1 inch), higher resolution (VGA→SVGA, XGA), wider viewing angle, lower power consumption, faster response time and wider operating temperature range are the main requirements. The ratio TFT: STN was expected to change from 30: 70 in 1995 to 70: 30 in 1996. This is not only due to the TFT overcapacity and price decrease, but also to the technical performance. A significant improvement of response time and viewing angle of STN displays is required, and multiline addressing is a promising alternative. For word processor applications, STN remain the dominating technology, but also for this application colour displays will be soon introduced.

2.2. *Desktop PC*

The display market for desktop PC and work station monitors is expected to grow from around 50 million in 1995 to 80 million in 2000; that means it is four to five times larger than the notebook PC market [11]. The most popular CRT sizes are 14 and 15 inch, but the 17 inch share is increasing. Corresponding LCD sizes are 12–15 inch and it is expected that 13–14 inch LCDs could reach a 5–10% market share in the next five years if price and viewing angle are acceptable. At present, the (in-plane switching) IPS-TFT-LCD [12, 13] looks most promising, and conventional TFT displays will only have a chance to compete if their viewing angle dependence is significantly improved. FLC displays have also been introduced to the market for work station application.

2.3. *Direct view TV*

For 40 inch HDTV application CRTs are inconvenient because of weight and size; therefore PDP and LCD are promising technologies for this application. TFT-LCD prototypes and plasma addressed LCDs (PA LCD) have been demonstrated, but before such products will be available in perhaps three to five years, 40 inch PDPs are already expected to be introduced to the market. Therefore, 10 inch TFT-LCDs remain at the moment the largest direct view LCD for TV application.

2.4. *Projection TV*

For rear- and front-projection TV, LCD-technology has to compete with the established CRT devices. Last year rear projection TVs using TFT-LCDs were introduced. For front projection single- and three-light-valve LCDs, systems based on TN-TFT technology are available, but brightness still needs to be improved. Therefore, PDLC-TFT or ECB-TFT are alternative technologies resulting in higher brightness.

2.5. *PDA*

Up to now monochrome STN displays have been utilized in PDAs and organizers. But also for this application, colour LCDs have been developed and several reflective colour STN prototypes with low power consumption have been demonstrated. Furthermore, new display modes have been introduced, e.g. OCB [14] and these are of interest for future reflective colour LCDs.

Important applications for LCDs are summarized in table 1 together with LCD technologies which are used today or expected to be used in the future.

3. Liquid crystal materials

For several applications, display properties such as viewing angle, response time and power consumption have to be improved. In order to achieve this goal, LC material properties must be optimized for several LCD technologies. Table 2 gives an overview of a few LCD properties which require improvement, including the different LCD technologies and important classes of LC materials. Examples for these different classes of LC materials will be introduced, together with the most relevant LC material properties, in the following paragraphs.

3.1. *Low optical anisotropy*

The viewing angle of TFT-LCDs still requires improvement, not only for notebook PC application but also for the desktop PC. LC materials with lower optical anisotropy contribute to this improvement, but also for new technologies like IPS or Plasmatron, LC materials with a small birefringence are required.

In figure 3 fluorinated LCs with different end groups are compared. By increasing the number of fluorine atoms in these 'CCP' structures (two cyclohexane and one phenyl ring) it is possible to increase the dielectric anisotropy and decrease the optical anisotropy. An appropriate selection and combination in mixtures allows the optimization of viscosity and other properties [10].

3.2. *High dielectric anisotropy*

For notebook PC application low power consumption is a key issue. Therefore, 3·3 V and even 2·5 V driving voltage are considered for TFT-LCDs. But other applications and technologies require LC materials for low driving voltages. LC materials with high dielectric anisotropy can be realized by increasing the number of fluorine atoms in 'CCP' structures (figure 4). It is also possible to optimize the viscosity by selecting the best positions for fluorine substitution [10].

3.3. *Low viscosity*

For almost all applications, a fast response time is required. Therefore, LC materials with low viscosity are essential for TFT and STN application. Such LC materials are two-ring compounds and some examples are summarized in figure 5. The 'PCH' structure (one phenyl and one cyclohexane ring) is utilized for TFT

Table 1. Applications and LCD technologies.

Application	TN TFT	IPS TFT	STN	MLA	PA LCD	ECB TFT	FLC
Notebook PC	◎	○	Δ	○	XX	X	X
Desktop PC	○	◎	Δ	Δ	Δ	Δ	Δ
Word processor	Δ	X	◎	○	XX	X	X
Direct view TV	○	○	XX	X	○	X	X
Projection TV	○	XX	XX	XX	XX	○	XX
PDA	○	XX	◎	X	XX	Δ	XX
Cellular phone	XX	XX	◎	XX	XX	XX	XX

Key: ◎ very good, ○ good, Δ moderate, X inferior, XX not suitable.

Table 2. LCD technologies, LCD properties and LC material classes.

LCD properties to be improved	LCD technologies: TN TFT	IPS TFT	STN	MLA	PA LCD	ECB TFT	Main LC material classes
Response time		x	x	x		x	
Viewing angle			x	x	x		
Driving voltage	x	x				x	
	x	x			x		Low Δn
	x	x					High $\Delta \varepsilon$
	x	x	x	x	x	x	Low γ_1
			x	x			High K_3/K_1
			x	x			High Δn
		x				x	negative $\Delta \varepsilon$

application, whereas 'CC' and 'CVC' structures (two cyclohexane rings) are optimized for STN application.

3.4. *High elastic constant ratio*

STN displays for notebook PC and PDA application require LC materials with fast response time and good threshold steepness. These properties can be improved by increasing the elastic constant ratio K_3/K_1 and decreasing the rotational viscosity. As shown in figure 6, the introduction of double bonds in 'CVCP' structures in the chain and between the rings increases the elastic constant ratio and improves the viscosity compared with ethyl bridged compounds. Very low viscosities can be achieved in CCP structures with one double bond in the chain.

3.5. *High optical anisotropy*

The response time of STN displays for notebook PC application has to be further improved in order to reach video rate. There are two promising technologies: multiline addressing (MLA) [15] and reduction of the cell gap [16]. In both cases LC materials with high optical anisotropy are required. Examples of such compounds are shown in figure 7. These are two-ring compounds with a triple bond, or three-ring materials like terphenyls.

3.6. *Negative dielectric anisotropy*

So far LC materials with negative dielectric anisotropy have only been utilized for the colour super homeotropic (CSH) mode [17], but recently these materials have also been of interest for ECB-TFT displays in projection devices or for in-plane switching (IPS). In the case of CSH the voltage holding ratio (VHR) was not an issue, but for TFT application, this important parameter has to be considered. Therefore, fluorinated LC materials with high VHR, low viscosity and large negative dielectric anisotropy have been identified, and their properties

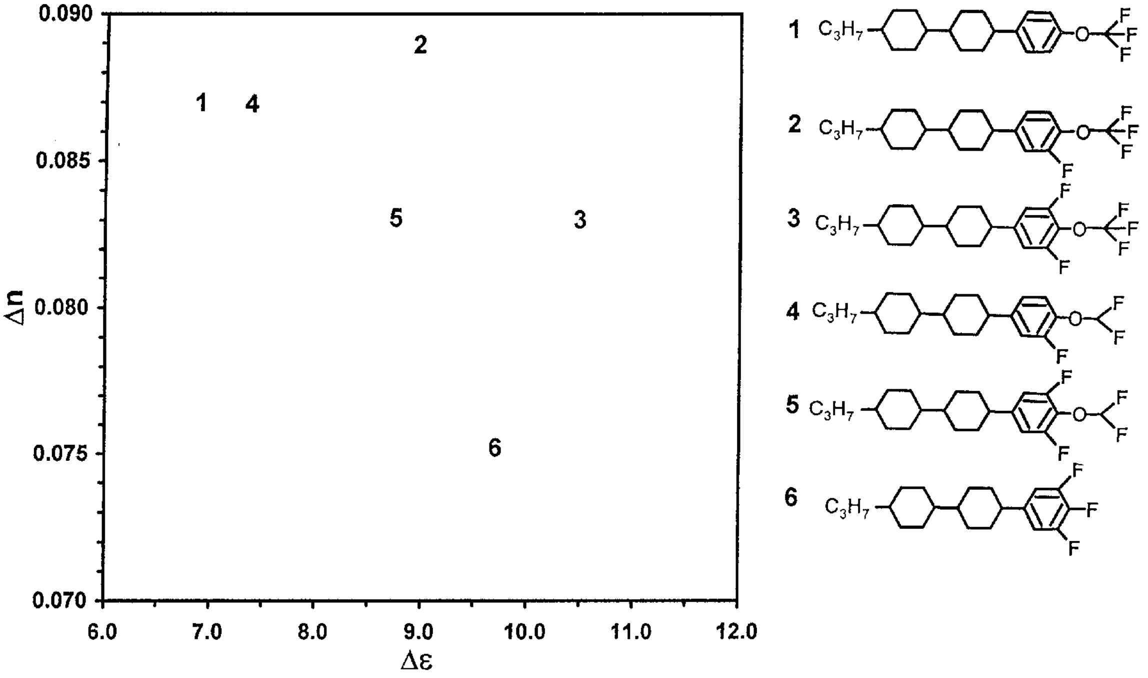

Figure 3. LC materials with low optical anisotropy, Δn.

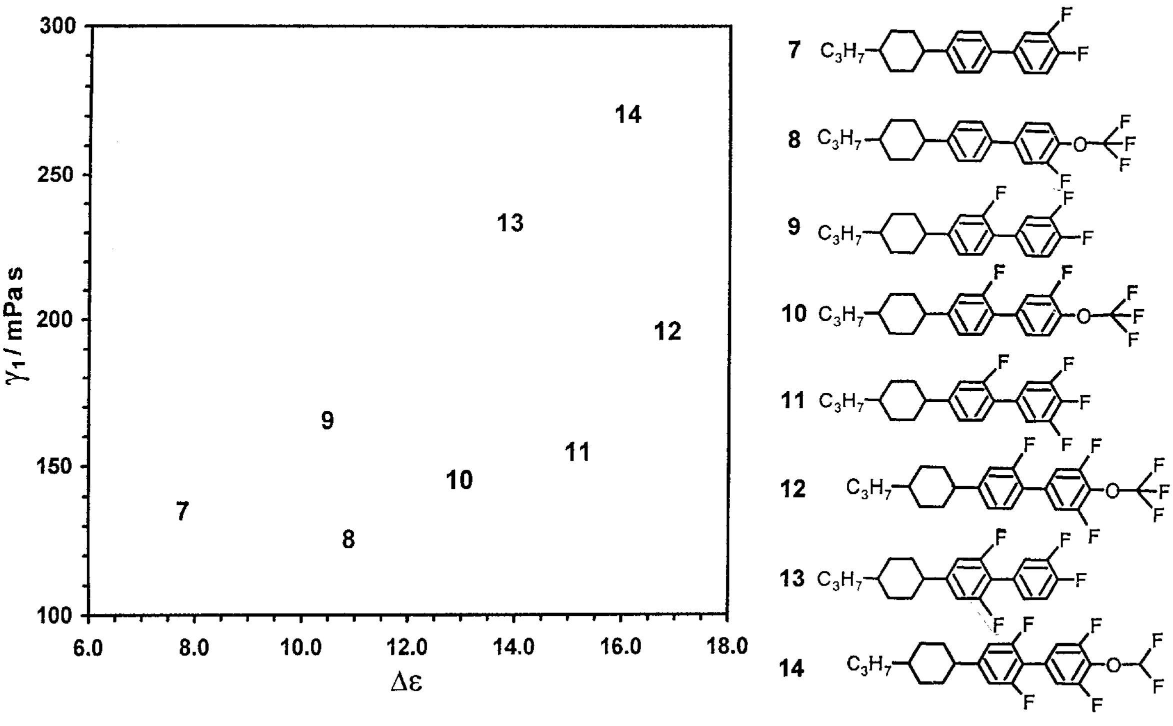

Figure 4. LC materials with high dielectric anisotropy, $\Delta\varepsilon$.

are compared in figure 8 with cyano compounds and esters [18].

4. Conclusion

The display market in general and the LCD market in particular show a very promising future. New technologies and operation modes always require optimized and new LC materials. Recent progress in LC materials development has been presented, and the trend to new LCD applications like desktop PCs and large size TVs is a challenge for material suppliers to contribute to the successful development. A better understanding of

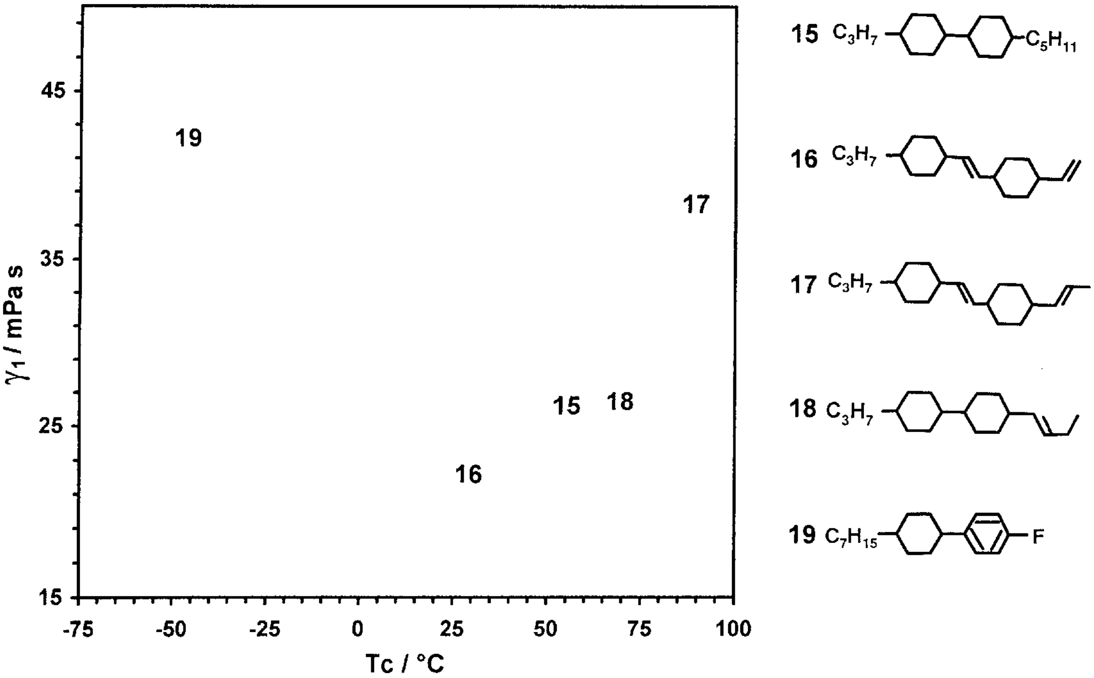

Figure 5. LC materials with low viscosity, γ_1.

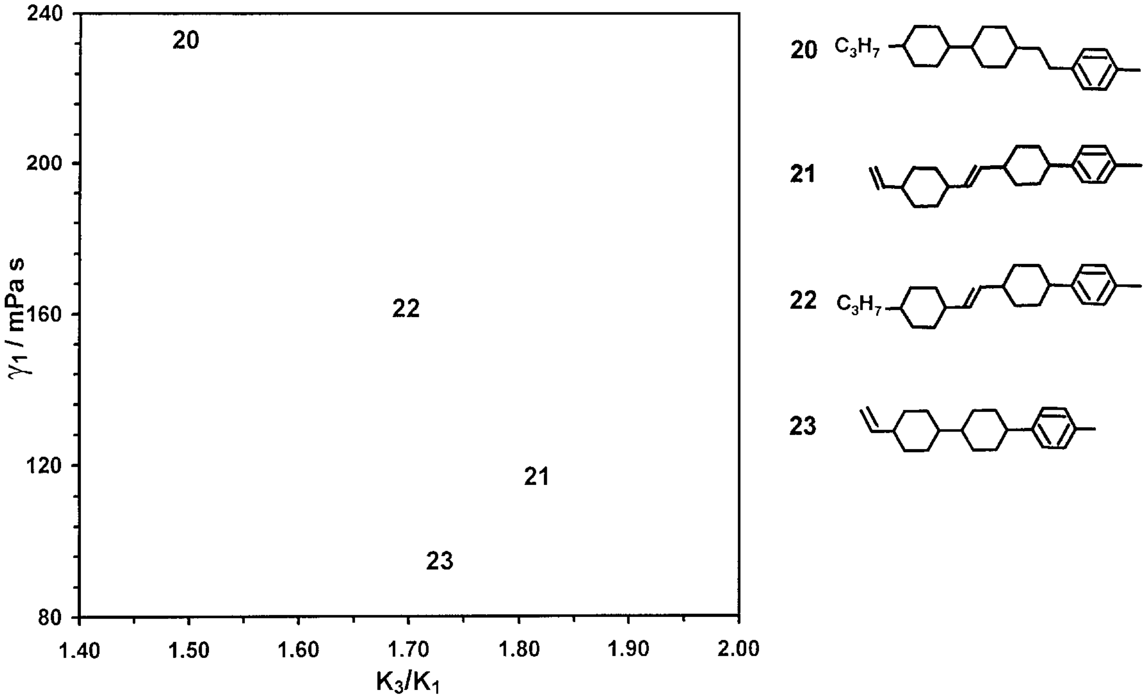

Figure 6. LC materials with high elastic constant ratio, K_3/K_1.

applications, technologies and LCD properties is a prerequisite to improved LC mixture properties, and to the development of improved LC single materials.

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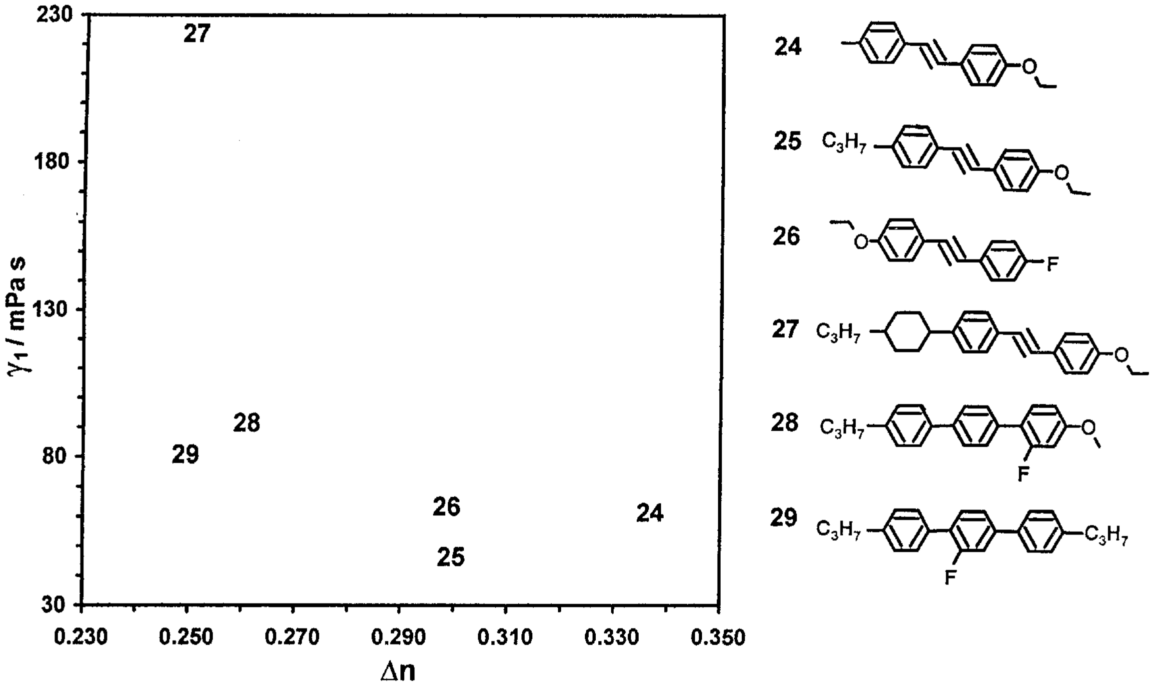

Figure 7. LC materials with high optical anisotropy, Δn.

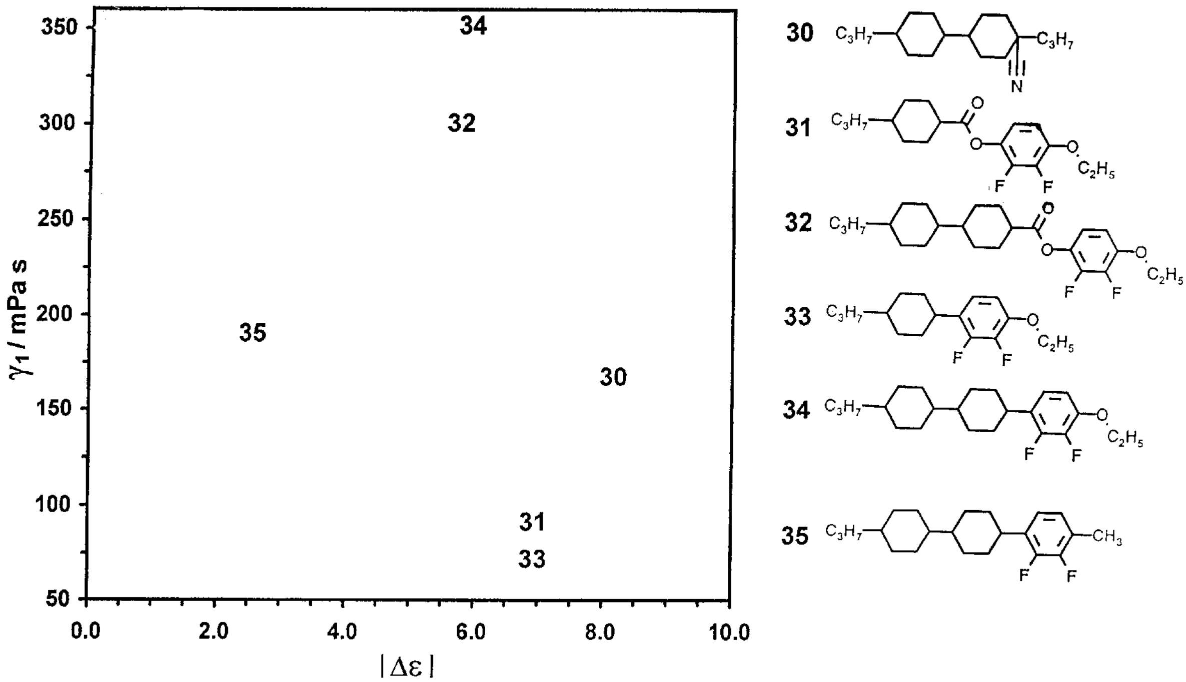

Figure 8. LC materials with negative dielectric anisotropy, $\Delta\varepsilon$.

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