PROGRESS OF LC ALIGNMENT THIN FILM MATERIALS FOR LCD

-Progress of LC Alignment Polyimide Materials for Rubbing Process and Development Situation of New LC Alignment Materials for Future Non-Rubbing Processes -

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I. Introduction

Full-color TFTs and STNs were developed in the middle of the 1980s. At this time, there was a heightening of interest in liquid crystal alignment film materials and liquid crystal alignment control techniques, and liquid crystal alignment control techniques were recognized as a key technology in influencing the display quality of LCDs. Ever since LCDs were first introduced, the rubbing technique has been the only method available to control liquid crystal alignment. However, as the applicability of TFTs expanded, it became necessary to use large-size glass boards, widen the viewing angle of LCDs, improve their brightness, and reduce the pixel size. As a result, over the past ten years, the limitations associated with the rubbing technique became clear, and people began to take a greater interest in non-rubbing techniques for controlling liquid crystal alignment. Furthermore, ever since photo-irradiation was shown to be a promising liquid crystal alignment control technique (photo-alignment technique) to widen the viewing angle, photo-alignment has been an area of much interest.

The present paper discusses the following topics: the reasons for people's interest in non-rubbing liquid crystal alignment techniques; what it is that makes photo-alignment techniques so popular; current research and development of photo-alignment techniques; technical issues associated with the commercialization of photo-alignment films; new non-rubbing techniques, besides photo-alignment techniques; advances in rubbing alignment film materials; the mechanism of the rubbing liquid crystal alignment technique; and the future of liquid crystal alignment.

2. Rubbing liquid crystal alignment control techniques

Before discussing non-rubbing liquid crystal alignment control techniques, it is important to understand the existing established rubbing liquid-crystal alignment control techniques used in actual mass production. Of particular importance is the relationship between LCD display characteristics and the molecular structure of alignment film materials, as well as the need to understand the overall mechanism of rubbing alignment.

2.1. Alignment film materials

Over an approximately ten-year period starting from the introduction of LCDs to that of full-color TFTs, low-Tg polymers, such as PVA, were first used as rubbing alignment film materials. It was at this time that various acrylic polymers and vinyl polymers were first analyzed. However, these materials are unsuitable as LCD materials due to their heat-resistant and solvent-resistant characteristics. Also, most heat-resistant polymers were unsuitable because they do not dissolve in solvents. However, it was found that polyimides (heat-resistant polymers), had a precursor called polyamic acid which dissolves in a polar solvent, thus making it possible to prepare a thin polyimide film by applying a thin layer of polyamic acid solution and heating this layer to induce imidization (Figure 1). As a result, polyimide thin film became the natural choice for rubbing alignment film materials[1].

When full-color TFTs were first developed in the early part of the 1980s, a staining method was employed to make color filters. However, these filters were not suitable for the above-mentioned high-temperature polyimide processing due to their heat-resistant and solvent-resistant characteristics, thus making the development of full-color TFTs very difficult. Nevertheless, the development of low-temperature soluble polyimides (Figure 2) enabled the commercialization of full-color TFTs[2]. Table 1 summarizes the development history of rubbing alignment film materials used for the production of full-color TFTs[3].

As far as display quality was concerned, the need to improve voltage holding ratio was first addressed, followed by the need to improve pre-tilt angle, wide viewing angle, and image sticking. Display requirements became markedly more stringent, and there was a demand for a technique that could satisfy these needs simultaneously. The key words for the molecular design of low-temperature soluble polyimides can be summarized as follows:

① Voltage holding ratio: low polarity and non-electron conjugation system
② Pre-tilt angle: introduction of a side-chain
③ Wide viewing angle: solvent resistance compatible with the pixel-division method
④ Image sticking: low-polarity polyimide

At present, as it is difficult for a single functionality to satisfy all of these needs using mono-polymers, a hybrid compound consisting of low-polarity polyimide and high-polarity polyamic acid is generally used.

2.2. Alignment mechanism

There is no established theory to explain the mechanism of rubbing liquid crystal alignment in which the surface of an alignment film is rubbed to align liquid crystal molecules.

Based on the results of various studies in the past, the author believes that the following factors are important in liquid crystal alignment:

① Rearrangement (alignment) of the molecular chains of polymers that occurs within several molecular layers on the surface of alignment films[5].
② Nano-size grooves (not micro-size grooves)6)
③ Surface morphology7)
④ Conformation of alignment film polymers8)
⑤ Interaction between the alignment film polymer molecules and liquid crystal molecules[9]

The above factors ① to ③ are based on the results of studies on rubbed surface observation, characteristic assessment, and model experiments. The factors ④ and ⑤ are grounded in molecular design techniques. Figure 3 shows the conceptual drawing for these factors. Practical liquid crystal alignment control techniques must satisfy not just one of these factors, but multiple factors simultaneously.

In recent years, Momoi and colleagues[10] employed the near-edge X-ray absorption fine structure (NEXAPS) spectrum method to clarify the molecular chain rearrangement. Ever since we investigated nano-size grooves in 1992, there have not been any further studies on this issue. Reports on micro-size grooves continued after that, and Nazarenko and colleagues[11] investigated this factor by atomic force microscopy (AFM) in 1998.

The author believes that ① and ② are important factors in liquid crystal alignment, and thus these factors should be investigated further when developing a non-rubbing liquid crystal alignment control technique.

3. Background issues explaining the popularity of non-rubbing alignment control techniques

Non-rubbing alignment control techniques first began to receive attention when full-color TFT manufacturing techniques were in their premature stage at the end of the 1980s and the early part of the 1990s. When seeking to improve brightness and ease-of-viewing and making displays larger and their pixels finer, there are limitations to the rubbing technique (Table 2). Consequently, the rubbing technique is essentially a technology of the past that is unsuitable for use in future TFT manufacturing.

Table 3 summarizes the state of patent applications on the non-rubbing technique in Japan, and Table 4 tabulates patent applications that were filed over a 13-year period between 1985 and 1997. LB films, magnetic fields, and mechanical actions were the main point of focus of non-rubbing alignment techniques in the early part of the 1990s, but these issues subsided after 1995.

A Japanese patent on photo-alignment first appeared in 1993. The applicant was Roche (of Switzerland), and the inventor was Dr. Schadt and colleagues. The patent deals with LCDs utilizing photo-alignment films made of polyvinyl cinnamate. A report dealing with this invention was published in 1992[12].

Between 1992 and 1994, studies were conducted to ascertain whether it is possible to widen the viewing angle of full-color TFTs by improving the alignment films. Hence, there was a great deal of interest in rubbing pixel-division alignment techniques. Koike and colleagues[13] were the first to report that the viewing angle could be improved by the pixel-division method. Consequently, research on the pixel-division method was conducted by various companies, such as JSR[14] and Toshiba[15]. Nevertheless, the consensus was that rubbing pixel-division alignment techniques are complicated, and are not attractive as practical manufacturing techniques.

Photo-alignment is a non-contact technique that allows pixels to be divided into any number of parts and aligned through the use of a mask. Researchers began to pay greater attention to this technique. Kobayashi and colleagues were the first in the world to show the usefulness of photo-alignment techniques. In 1995[16], they documented that by dividing each pixel into four parts, favorable viewing angles could be obtained without further division. At this time, Ichimura and colleagues[17] coined the term "command surface" to describe a photo-alignment technique based on the photo-isomerization of the azobenzene group. Gibbon and colleagues[18] reported that photo-alignment could be achieved by the photo-isomerization of diazo dies. And Hasegawa and colleagues[19] irradiated polarized UV to soluble polyimides (Figure 2) to control liquid crystal alignment.

The author believes that photo-alignment is popular because it shows much promise for those wishing to widen the viewing angle of TFTs. Also, there have been many reports on photo-alignment materials besides polyvinyl cinnamate.

4. Advances in photo-alignment techniques

4.1. Classification of photo-alignment techniques

Photo-alignment techniques were classified by Kobayashi and colleagues[20] (Table 5). In 1997, Ikeda and colleagues[21] reported a new mode of photo-alignment utilizing BPDA/DPE ether-bond polyimide that could not be classified by this system.

In photo-decomposition alignment, laser irradiation decomposes and gasifies polymers to etch the polymer surface, and the resulting functional grooves aligns liquid crystal molecules[22). Table 5 shows a typical technique for each mode of photo-alignment. When the common polyimide used in photo-decomposition is irradiated with UV light, the main chain of these polymers is partially cut, but the radicals generated during this process form crosslinking structures by intermolecular bonds. Since the resulting structure is insoluble in solvents, this photo-decomposition-crosslinking alignment should be distinguished from the above-mentioned photo-decomposition alignment. Nishikawa and colleagues[23)] identified polyimide having a cyclobutane ring as its main chain as a photo-alignment material used in photo-decomposition-crosslinking alignment. Also, a polyimide with a benzophenone-skeleton was reported as a photo-alignment material for photo-crosslinking alignment (Figure 4)[24)].

Table 6 shows the new classification system for photo-alignment techniques proposed by the author.

4.2. Trends in the development of photo-alignment techniques

Trends in the development of photo-alignment techniques after 1997 are discussed according to the classification system shown in Table 6.

(1) Photo-isomerization mode

The Material Research Group (Ichimura) at the Department of Engineering of Tokyo Institute of Technology reported that, by utilizing polymers having azobenzene as a side chain, liquid crystal molecules became aligned when irradiated with non-polarized light[25)]. Photo-alignment techniques utilizing non-polarizing light appear to hold promise as manufacturing techniques. Takesoe, Kakimoto and colleagues[26)] reported that stable TN LCDs could be produced by introducing the azobenzen group to the main chain of polyimide.

(2) Photo-dimerization mode

There have been several studies to develop photo-alignment materials, besides polyvinyl cinnamate. In one such method, multidomain TFT LCDs are produced using altered polysilane in which the cinnamoyl group is introduced to polysilane (Figure 5 (I))[27)]. In another, after reacting trialkoxysilane alkylamine with -OH groups on the glass surface, the terminal $-NH_2$ is allowed to react with the acid chloride of cinnamoyl. Consequently, photo-alignment is achieved by the photo-dimerization of the cinnamoyl group[28)]. Another study investigated the photo-alignment behaviors of side-chain type liquid crystal macromolecules, with a photo reactive mesogen, utilizing the photo reactivity of the cinnamoil group, and identified the effects of spacers that connect mesogen and cinnamoyl/mesogen on the photo irradiation direction and the alignment direction (vertical or horizontal) of liquid crystal molecules[29].

When irradiated with UV light, the cinnamoyl group undergoes cis-trans isomerization and photo-dimerization simultaneously. Since photo-alignment utilizing the cinnamoil group is based on two alignment mechanisms, namely photo-isomerization and photo-dimerization, the stability of alignment could be compromised.

There are functional groups with which UV light irradiation does not induce photo-isomerization. Schadt and colleagues introduced a coumarin group (Figure 5 (II))[30)]. They used this material (polyvinyl coumarin) to experimentally produce dual-domain TFT LCDs, and reported that they were able to develop highly reliable full-color TFT LCDs with a favorable viewing angle[31)].

My colleagues and I thought that the UV light (200-300 nm) used in photo-alignment would be unsuitable since this range of UV light oxidizes polymer surfaces. Hence, we discovered the 4'-chalcone group (Figure 5 (IV)). With this functional group, photo-dimerization occurs at a longer wavelength of 366 nm without inducing oxidation. We published its photo-alignment characteristics in a report[32]. However, photo-isomerization still occurred at this wavelength, thus compromising stability. Then, we identified the 4-chalcone group (Figure 5 (III)) as a functional group with which photo-dimerization occurs without inducing photo-isomerization at the longer wavelength[33]. The dimerization rate of the 4-chalcone group is high, and the heat resistance of the resulting polymer was also favorable (Figure 6). A photo-alignment technique could be practical if liquid crystal molecules align parallel to the optical axis of photo irradiation with a single photoirradiation to introduce a pre-tilt angle. The existing photo-alignment techniques require two irradiations. My colleagues and I synthesized a new photo-alignment material having a spacer structure between the 4-chalcone group and the polymer main chain, and documented that liquid crystal molecules aligned parallel to the optical axis with a single photoirradiation, thus resulting in stable TN LCDs[34]. Figures 7 and 8 and Table 7 show this new photo-alignment material and its photo-alignment characteristics.

(3) Photo-decomposition-crosslinking mode

When light is irradiated in an environment where radical generation and radical addition reactions are likely to occur, the additive attaches to the general area of the radical to introduce a pre-tilt angle. These findings were reported using soluble polyimide (Figure 2)[35]. Also, by investigating the alignment behaviors of liquid crystal molecules in the photo-alignment of polyimides having a cyclobutane ring as its main chain structure, my colleagues and I reported that polyimide with a fluorene structure was the only polymer that aligned parallel to the optical axis (Table 8) 22). Furthermore, when introducing a pre-tilt angle, side-chain structures are as important as is the case with rubbing alignment films.

(4) Photo crosslinking mode

The above-mentioned polyimide with a benzophenone skeleton is the only known polymer to be used in this type of photo-alignment mode.

(5) New mode

The above-mentioned BPDA/DPE polyimide is the only known polymer to be used in this type of photo-alignment mode.

In addition to these studies on the mechanism of photo-alignment, there have been reports on changes in the polyimide film surface brought about by photo-alignment[36][37]. In both cases, UV light of less than 300 nm was irradiated, and -OH and -COOH were observed on the surface of the polyimides. However, the resulting functional group negatively affected the image sticking (display quality) of TFT LCDs made from rubbing alignment film materials, thus suggesting that photoirradiation that causes the formation of polar groups may not be practical.

4.3. New non-rubbing liquid crystal alignment control techniques

At present, photo-alignment techniques are the only published non-rubbing alignment techniques. My colleagues and I agree with Hasegawa[38] in that the polyimides used with the rubbing technique are suitable for non-rubbing techniques when analyzing the overview of the TFT LCD manufacturing procedure. Therefore, we have been investigating methods to align liquid crystal molecules using the existing rubbing alignment films without rubbing. We were able to conclude that the alignment of liquid crystal molecules can be controlled by the use of pulse-laser, and we presented this new liquid crystal alignment control technique at the Euro Display '99 (Berlin)[39][40]. Figure 9 shows a conceptual drawing of the pulse laser apparatus. Experiments were conducted using various polyimides, and even though the conditions under which liquid crystal molecules were aligned parallel to the optical axis of the laser beam varied depending on the structure of polymers, parallel alignment could be more easily achieved by pulse laser than by photo-alignment (Figure 10). Also, the thermal stability of the resulting liquid crystal alignment was better than that for the previous photo-alignment techniques (Figure 11).

5. Current state of photo-alignment techniques

Currently, photo-alignment techniques are the main focus of research on non-rubbing liquid crystal alignment control, and the state of their development was discussed above. This section deals with the author's views on the following questions: Are photo-alignment techniques ready to replace the existing rubbing technique? And what is the stage of research and development on the current photo-alignment techniques?

The author has carried out R&D by dividing it into different stages, from basic research to production, as shown in table 9. Various photo-alignment techniques have been introduced (table 6), but research in this area has concentrated on the photo-alignment material, wavelength of irradiated light, introduction of a pre-tilt angle, and improvements in the viewing angle.

One group of users who most eagerly await the completion of photo-alignment techniques are TFT makers. Nevertheless, there have not been many studies on factors that affect the display quality of TFT LCDs: voltage holding ratio, tilt angle, image sticking, heat resistance, solvent resistance, moisture resistance, and light resistance. Unlike the case with rubbing alignment films, there have not been any reports on the relationship between the display quality of LCDs and the molecular structure of photo-alignment materials. Hence, the current photo-alignment techniques appear to be somewhere between the basic research and applied research stages, but closer to the applied research stage.

When Korean researchers from LG Electronics introduced their TFT LCDs utilizing photo-alignment techniques at the Electronics Show 1997 and Asia Display 1998, it appeared that these TFT LCDs would be in production in the very near future, but the author now believes that their TFT LCDs were trial products to ascertain the possibility and commercialization capability of TFT LCDs employing photo-alignment techniques. These TFT LCDs are, therefore, in the applied research stage. Nonetheless, due to the rapid advances in this area of research and development, it is possible that they are in the early development stage.

6. Future technical issues and prospective

Important characteristics associated with the display quality of TFT LCDs are analyzed below to ascertain the advances made in non-rubbing liquid crystal alignment control techniques.

(1) Voltage holding ratio

So far, maleimide-styrene copolymer (PMI-6 in Ffigure 7) having the 4-chalcone group in its side chain via a spacer is the only polymer that satisfied a voltage holding ratio of 96.4%, which is the level considered acceptable. However, the residual DC characteristics (image sticking) of this polymer are not favorable.

(2) Pre-tilt angle

As mentioned above, there have been many reports on the introduction of a pre-tilt angle, but there is no published technique that could introduce any pre-tilt angle between 0 and 90 degrees in a stable fashion. Techniques related to pre-tilt angle introduction are still being developed.

(3) Image sticking

Hasegawa conducted a study using soluble polyimides, and reported that, with a photoirradiation energy of 1 J/cm^2, there were no problems in adhering polyimides onto actual panels[38]. To the best of my knowledge, there have been no other reports in this area of research.

(4) Anchoring strength

Anchoring strength is thought to influence image quality, viewing angle, and response speed. In the past, the anchoring strength for photo-aligned liquid crystal molecules was low, about 1/10 - 1/100 that of rubbed liquid crystal molecules (in the order of 10^{-3} J/m^2). Therefore, there are still questions about the reliability of photo-aligned liquid crystal molecules.

In recent years, my colleagues and I have attempted to improve the above-mentioned maleimide photo-alignment material (Figure 12: PMI-15). When light was irradiated with a temperature above Tg, the resulting anchoring strength was comparable to the anchoring strength of rubbed polyimides (Figures 13 and 14)[41].

Therefore, a non-rubbing technique that satisfies all of these display characteristics of TFT LCDs has not yet been established, but it is highly possible that such technology will be available sometime in the future. At present, the most promising techniques appear to be those that employ the above-mentioned maleimide photo-alignment material (PMI-15) and polyimides used in rubbing alignment films. The practical application of non-rubbing techniques will depend on future collaboration among material, device, and equipment makers.

As for advances in the fields of applied photo-alignment control techniques, Schadt and colleagues[42] sprayed a photo-alignment material, which they had developed, onto a film, and after forming a liquid crystal alignment control surface by photo irradiation, the functional monomer of cholesteric liquid crystal was applied to align the liquid crystal monomers. Then, the stretching liquid crystal molecules were fixed by photo-curing to produce an optically functional film. This film utilizes the optical isomerization of liquid crystals, as is the case with wide viewing-angle films utilizing the optical isomerization of the commercially available drawing liquid crystal macromolecules. This suggests that, after reforming the surface by means of a non-rubbing liquid crystal alignment control technique, liquid crystal monomers can be applied to design materials with various optical isomerization characteristics. Consequently, non-rubbing liquid crystal alignment control techniques will open new frontiers in the field of applied liquid crystal research.

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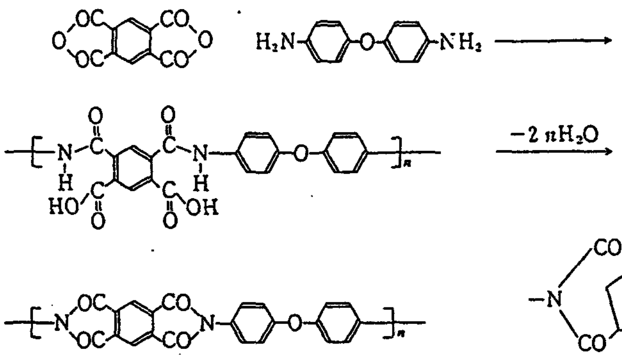


Fig.1 Route of polyimide synthesis.

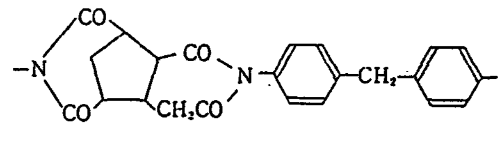


Fig.2 Soluble polyimide.

Table 1. Development history of full-color TFT alignment film materials

Year	Requirement of Alignment Material for TFT LCD	Molecular Design	Practical PI Structure
1984	· Low Temp. Processing (aptitude for CF) · Voltage Holding Ratio	· Soluble PI Structure · Non Conjugated Structure	Cyclo-Aliphatic (acid) / Aromatic (amine)
	· Pre-tilt Angle Generation	· Introduction of Side Chain	Side chain type Cyclo-aliphatic (acid) / Aromatic (amine)
	· Improvement of View Angle	· Resistance for Solvents in photo resist	· Side chain type Cyclo-Aliphatic (acid) / Aromatic (amine) · Side chain type; introduced Cross Linking Groups
Present	· No Image Sticking	· Fast Diffusion of Impurity Materials in LC to Alignment low layer	· Hybrid materials of soluble cyclo-aliphatic(acid) / aromatic(amine)PI (Low polarity) and High Polarity PA

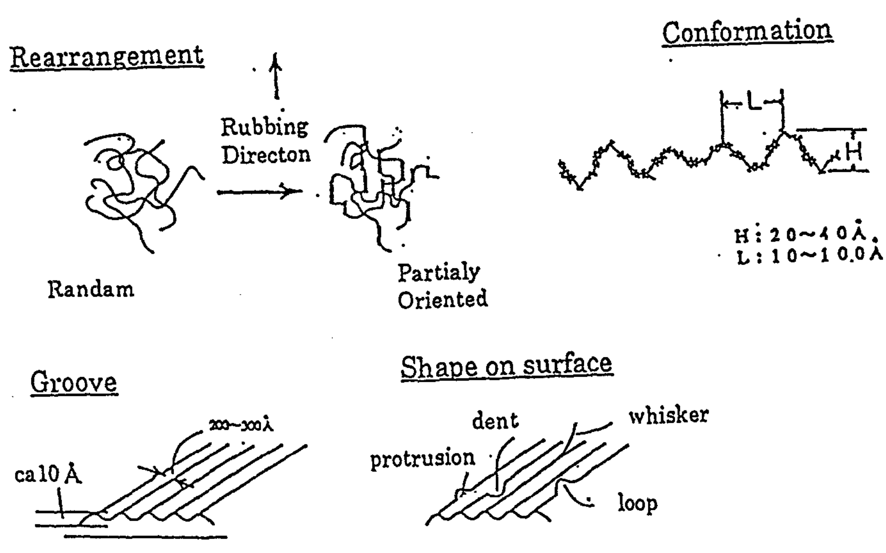


Fig.3 Image models of liquid crystal alignment generation factors.

Table 2. Technical issues associated with rubbing

1. Static electricity	Devices are equipped with an anti-static function to prevent the destruction of TFT elements, but this measure is not fool-proof.
2. Dust generation	When a washing procedure is required, the number of manufacturing processes increases.
3. Uniformity	Rubbing conditions vary at step and flat areas, thus causing unevenness in alignment control force and tilt angle introduction.
4. Separation alignment of pixels	Since rubbing is unidirectional, the manufacturing procedure becomes complicated.
5. Large board adaptability	A device that can evenly rub large boards, more than a meter in size, is needed.

Table 3. Classification of non-rubbing alignment techniques

Technique classification	Number of patents	Note
1. Alignment film material	4	Charge-transfer complex film (TTE-TCNQ) (FLC)
2. LB membrane	28	
Polymer structure	(18)	Aromatic compound, polyimide, alkylcarboxylate, polyimide precursor, protein, silane surface active agent, polyacrylic ester, phthalocyanine-derivative polyimide
Board nonuniformity	(6)	Photolithography is used to generate nonuniformity on the glass surface, ITO is subjected to the nonuniformity process, nonuniformity is generated by photosensitive resist, or macromolecular liquid crystal is used.
Others	(4)	Film forming methods (expansion, film pressure control, and board washing injection method)
3. Oblique vapor deposition	11	Materials and processes
4. Light	23	Polarized light irradiation, photo-dimerization, crosslinking and heat processing of liquid crystal polymers, polysilane (group formation), and photo crosslinking
5. Electron beam/laser beam	8	Groove formation on the surface (electron beam)
6. Ion beam	11	Groove formation by ion etching, adjusting the pre-tilt angle by the ion shower angle, and ion beam/electron beam
7. Magnetic field	10	Liquid crystal polymers, photo-curing type acrylic compounds, ferromagnetic particle dispersion, LB membranes, and liquid crystal molecules
8. Electric field	1	Electric field/ laser
9. Ultrasound/ vibration	2	The interference waves of surface acoustic waves are swept in one direction so as to vibrate the injected liquid crystal by piezoelectric elements.
10. Heat	2	Liquid crystal molecules, and liquid crystal molecule alignment by light/heat.
11. Mechanical action	12	Accelerating ferromagnetic materials using magnetic fields to make them collide, pressure welding vibrating materials by electrostrictive effects, passing particle dispersion liquid along in one direction, heat-spraying on liquid crystal polymers, or spraying (board, fine frozen water, gap agent).
12. Chemical action	5	
Chemical modification	(2)	Liquid crystals are added to the PVA surface (-OH), and after the alignment film surface is carbonized by UV/ozone and plasma etching, macro ring compounds are allowed to react (-OH and -COOH).
Polymerization reaction	(3)	LB membranes are irradiated with an X-ray (group), liquid crystal monomers are polymerized in a magnetic or electric field, or palyimides are polymerized by heat-decomposition.
13. Photolithography	8	Groove are formed using photosensitive polymers (LB membrane, coating membrane), or periodic non-uniformity patterns are used.
14. Copying	2	Copy using specified non-uniformity patterns.

Table 4. Patents classified according to type and year of disclosure

Technique classification	Number of patents	Year of disclosure												
		85	86	87	88	89	90	91	92	93	94	95	96	97
1. Alignment film material	4							1	2	1				
2. LB membrane	28			5		1	5	5	2	6	3		1	
3. Oblique vapor deposition	11				1		3	3	2	1			1	
4. Light	23									1	2	8	6	6
5. Electron beam/laser beam	8						1			3	2		1	1
6. Ion beam	11						1	1	1		3	1	2	2
7. Magnetic field	10		1				2	1	3	2				1
8. Electric field	1										1			
9. Ultrasonic/ vibration	2						2							
10. Heat	2							1	1					
11. Mechanical action	12						5	1		1		3	1	1
12. Chemical action	5			1	1		1		1	1				
13. Photolithography	8					3		1	1		2		1	
14. Copying	2				1					1				

Table 5. Classification of the photo-alignment methods

Methods	Example
1. Photo-isomerization	Photo-isomerization of the azo group (cis-trans)
2. Photo-dimerization	Photo-dimerization of the cinnamoyl group
3. Photo-decomposition	UV light irradiation onto a soluble polyimide

Table 6. New classification of the photo-alignment methods

Technique	Main example
1. Photo-isomerization	Photo-isomerization of the azo group
2. Photo-dimerization	cinnamoyl group, coumarin group, chalcone group
3. Photo-decomposition-cross-linking	Photo-irradiation onto a soluble polyimide and cyclo-butane polyimide
4. Photo cross-linking	Photo-irradiation onto benzophenone polyimide
5. Photo-decomposition	micro group formation by laser abrasion
6. New mode	Photo-irradiation onto BPDA/DPE polyimide

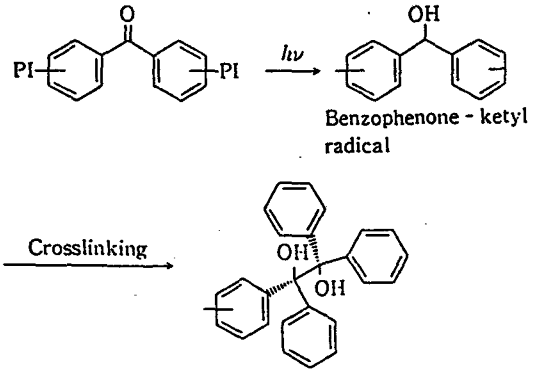


Fig.4 Scheme of photo - crosslinking and photo - alignment.

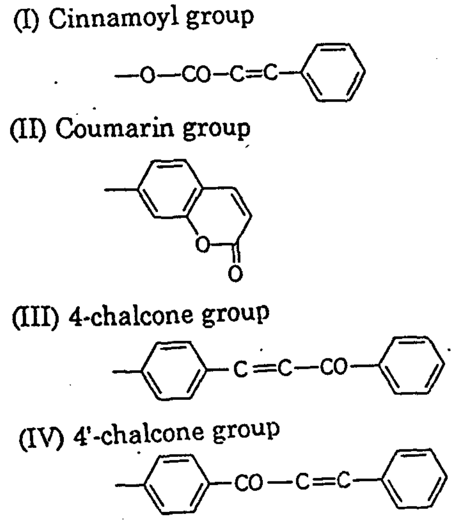
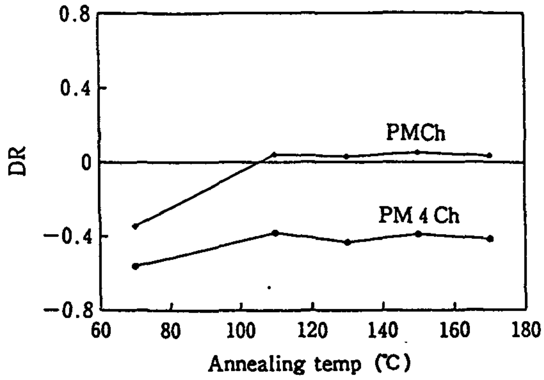


Fig.5 Functional groups of photo - dimerization.



Annealing condition: 10 minutes
PMCh: polyacrylic 4'-chalcone
PM4Ch: polyacrylic 4-chalcone

Fig.6 Heat-resistance of photo - alignment material films.

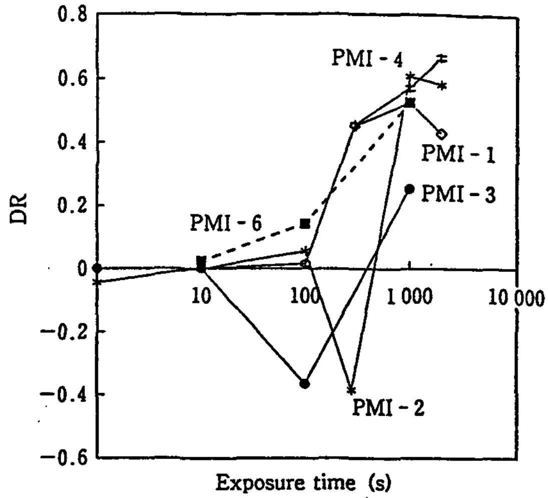


Fig.8 Characteristics of new photo - alignment materials.

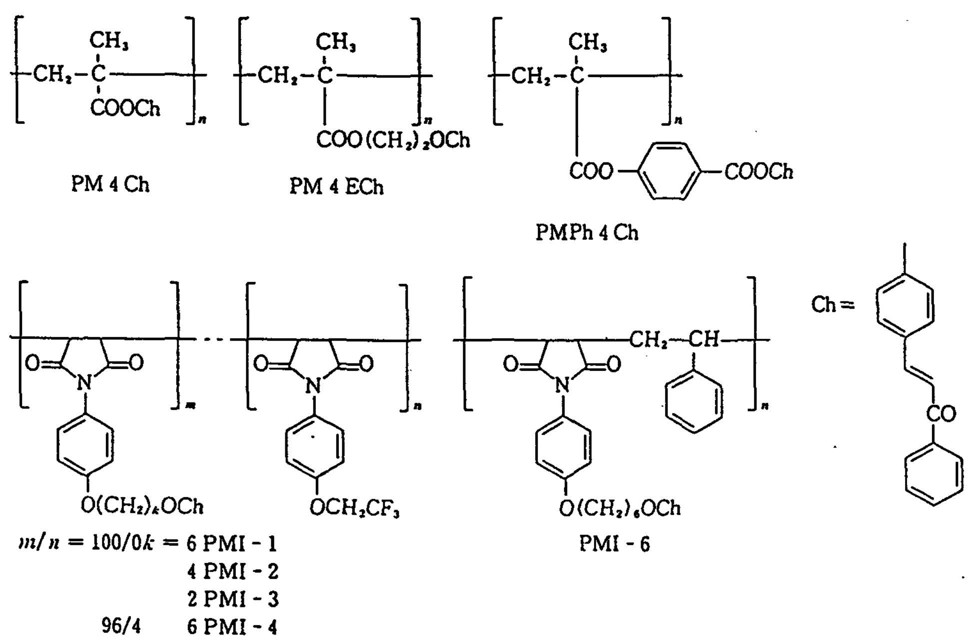


Fig.7 New photo - alignment materials.

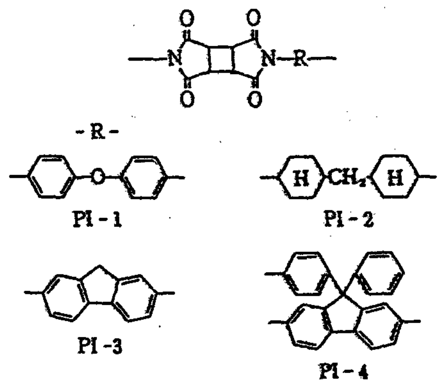
Table 7 Pretilt angle (θ_p) generation by a slantwise LPUV exposure

Material	Exposure condition		θ_p
	Polar angle (deg)	Dose (J/cm²)	(deg)
PMI - 1	60	3.3	<0.1
PMI - 4	60	3.3	1.2
PMI - 6	45	5.7	5.3(*)

* : Deviation in a cell was pretty large (±2°)

Table 8 LC alignment on PIs

-R-	LC alignment direction	
	Rubbing	Polarized UV
PI-1	//	⊥
PI-2	//	⊥
PI-3	//	⊥
PI-4	⊥	//



Chemical structures of PIs

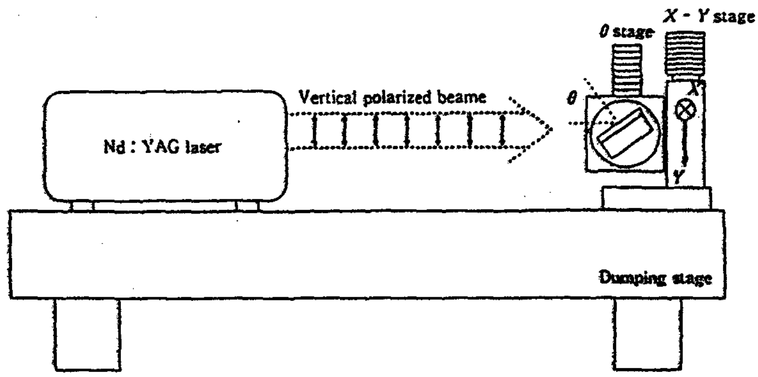
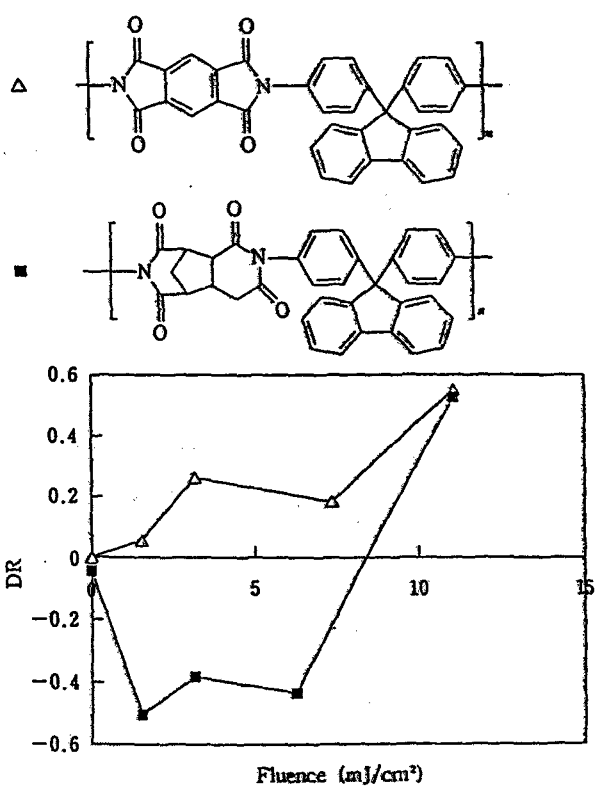
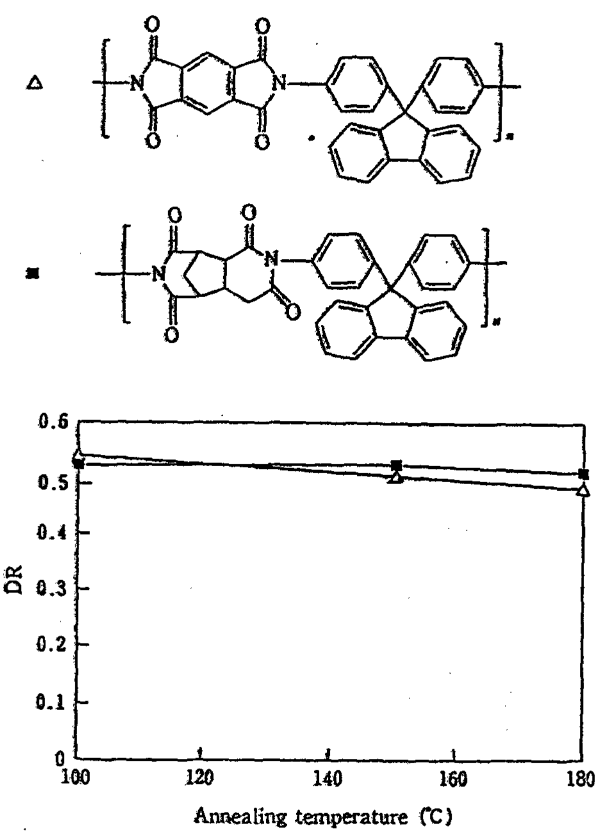


Fig.9 Scheme of pulse - laser irradiation equipment.



Photoirradiation at 11 mJ/cm² in air

Fig.10 Regulation of liquid crystal alignment by pulse - laser irradiation.



Photoirradiation at 11 mJ/cm² in air

Fig.11 Thermal stability of regulated liquid crystal alignment surface by pulse - laser irradiation.

Table 9. Stages of research and development from basic research to production

R&D stages	Contents
Basic research (2 years)	• Sow appropriate seeds to match the needs
Applied research (2 years)	• Ascertain how promising materials and technologies should be applied. • Establish a business plan for possible applications by taking economic considerations into account.
Early-development (2 years)	• Solve technical issues associated with the promising materials and techniques to implement the business plan. • Organize commercialization plans.
Late-development (2 years)	• Solve issues associated with consistency between product development and manufacturing. • Assess feasibility.
Production	

PMI-15

AL-1254

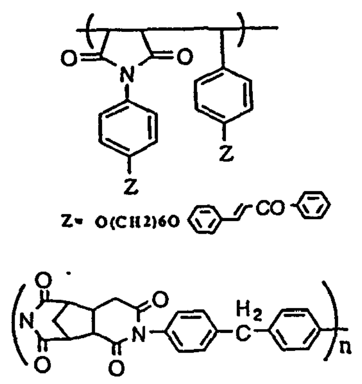


Fig.12 The chemical structures of PMI-15 and A

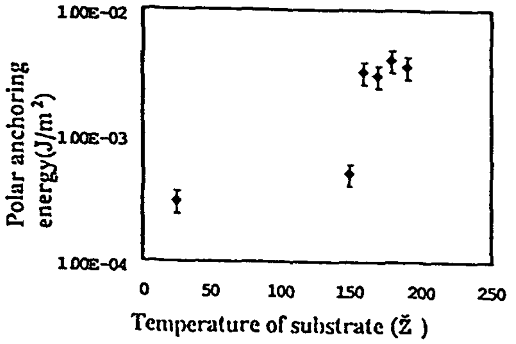


Fig.13 Polar anchoring energy between MLC-6221 and the surface of PMI-15 film at various irradiation temperatures.

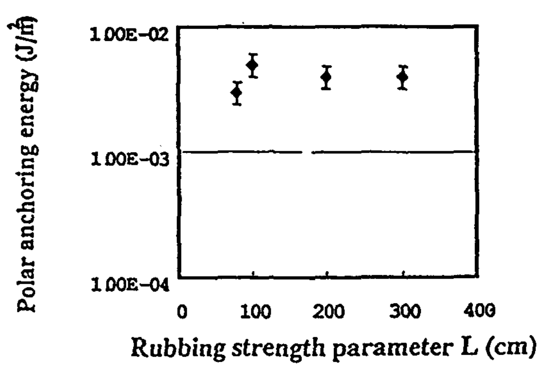


Fig.14 Polar anchoring enegy between MLC-6211 and the surface of AL-1254 film.