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Introduction

Among all the flat panel display technologies, liquid crystal display (LCD) is the most dominant. The manufacture of LCDs is now very mature and done with huge glass substrates measuring over 5 m^2. The availability of such inexpensive high-resolution displays has accelerated the transformation of our society into a display-centric one. However, despite its dominance, LCD is still in need of further improvement. Among other things, light utilization efficiency, cost, and optical performance such as response times of LCD are still not optimal. It is no wonder that much research is still being performed and new LCD modes are still being invented with better properties such as response time or viewing angles.

In this book, we concentrate on one aspect of LCD manufacture, namely that of the alignment surface. In particular, we shall present a comprehensive review of photoalignment technologies. Photoalignment has been proposed and studied for a long time [1–12]. In fact, the subject of light–molecule interactions has been a fascinating subject of research for a long time and is still capturing the imagination of many people. Light is responsible for the delivery of energy as well as phase and polarization information to materials systems. In this particular case, the alignment of the molecules takes place due to a partial ordering of the molecular fragments

Photoalignment of Liquid Crystalline Materials: Physics and Applications
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after a topochemical reaction of a photoselection (Weigert's effect). While the first photo-patterned optical elements, based on polyvinyl-cinnamate films, appeared in 1977 [1], the technology became an LCD one only at the beginning of the 1990s [2–5]. It was soon shown that these materials could provide high-quality alignment of molecules in an LC cell. Over the last 20 years, many improvements and variations have been made for photoalignment. Commercial photoalignment materials are now readily available. Many new applications, in addition to the alignment of LCD, have been proposed and demonstrated. In particular, the application of photoalignment to active optical elements in optical signal processing and communications is currently a hot topic in photonics research.

Photoalignment possesses obvious advantages in comparison with the usually 'rubbing' treatment of the substrates of LCD cells. Possible benefits for using this technique include:

1. Elimination of electrostatic charges and impurities as well as mechanical damage of the surface.
2. A controllable pretilt angle and anchoring energy of the LC cell, as well as its high thermal and UV stability and ionic purity.
3. The possibility to produce structures with the required LC director alignment within the selected areas of the cell, thus allowing pixel dividing to enable new special LC device configurations for transflective, multidomain, 3D, and other new display types.
4. A potential increase of manufacturing yield, especially in LCDs with active matrix addressing, where the pixels of a high-resolution LCD screen are driven by thin film transistors on a silicon substrate.
5. New advanced applications of LCs in fiber communications, optical data processing, holography, and other fields, where the traditional rubbing LC alignment is not possible due to the sophisticated geometry of the LC cell and/or high spatial resolution of the processing system.
6. The ability for efficient LC alignment on curved and flexible substrates.
7. Manufacturing of new optical elements for LC technology, such as patterned polarizers and phase retarders, tunable optical filters, polarization non-sensitive optical lenses, with voltage-controllable focal distance etc.

With all these new developments in photoalignment technologies, it is now the right time to take an inventory of the progress made over the last 20 years in the form of a monograph. This book presents the status of the research in LCD photoalignment and photo-patterning. To the best of our knowledge, there are no other books devoted to the subject, though a few review articles are available [6–11]. In this book, we shall concentrate on a recent approach of ours, which is rather promising, namely the photoinduced reorientation of azo-dyes [12]. This technique of photoalignment does not involve any photochemical or structural transformations of the molecules. Further, the new photoaligning films are robust and possess rather good aligning properties such as anchoring energies and voltage holding ratios. They can be very useful for the new generation of LC devices as well as in new photovoltaic, optoelectronic, and photonic devices based on highly ordered thin organic layers. Examples of such applications are light-emitting diodes (OLEDs), solar cells, optical data storage, and holographic memory devices. The novel and highly ordered layer structures of organic molecules may exhibit certain physical properties, which are similar to the aligned LC layers.

This book is intended for a wide audience including engineers, scientists, and managers, who wish to understand the physical origins of the photoaligning technique, its basic advantages and limitations, as well as the application for LC devices, including displays, optical waveguides, optical polarizers and retarders, etc. University researchers and students who specialize in condensed matter physics and LC device development should also find some useful information here.

The principal aims of the book are:

1. To describe the physical mechanisms of LC photoalignment with a special emphasis on the most useful photosensitive materials and preparation procedures suitable for the purpose.
2. To summarize LC surface interaction in photoaligned LC cells to produce the required LC pretilt angles, anchoring energy, ionic purity, IR and UV stability, and sensitivity to the activating light exposure.
3. To show how to produce perfect vertical, twisted, rewritable, and other LC photoalignment in nematic, ferroelectric, lyotropic, and discotic materials on glass and plastic substrates and special LC cell configurations (Si waveguide and 3D surfaces, superthin tubes, etc.).
4. To compare various applications of photoalignment technology for in-cell patterned polarizers and phase retarders, transflective and microdisplays, security and other LC devices.

5. To present recent results in applications of photoaligning and photo-patterning technology in LC devices.

The organization of this book is as follows. In Chapter 2, we shall present the various photoalignment mechanisms. Here the photoaligning techniques will be described and compared. In Chapter 3, the alignment properties of the various films will be discussed, with an emphasis on the azo-dyes. Properties such as anchoring energies and voltage holding ratios are important to LCD applications and will be discussed in detail. In Chapter 4, the application of photoalignment to various LCD modes and LC applications will be presented. Photoalignment on unconventional substrates will also be described to illustrate the power of such a technique. In Chapter 5, various applications of photoalignment to the fabrication of optical elements will be explored. The use of photoalignment to improve the design of transflective displays will be presented as well. Some applications of photoaligning technology for the development of new LC displays and photonic devices are then listed in Chapter 6. The working prototypes of new photoaligned LC devices, e.g. optically rewritable electronic paper, look very promising for future applications. One special feature of the book is a compilation of the most important patents, which forms Chapter 7. They are also classified in various ways for easy comprehension of where the technology is heading. We believe such a compilation will be very useful to readers.

The topic of this book is of particular interest to us, as we have undertaken some of the pioneering research in the field. In a sense it is a form of stock taking for us. We hope that the book will stimulate new research and development in the field of LC photoalignment and enable the technology to be used in large-scale LCD production. We are grateful to many colleagues who have worked with us in the past and are still working with us at the Center for Display Research in the Hong Kong University of Science and Technology, including E. P. Pozhidaev, W. C. Yip, Fion Yeung, Jacob Ho, Y. W. Li, A. Muravsky, A. Murauski, O. Yaroshchuk, A. Kiselev, V. Shibaev, S. A. Pikin, A. Verevochnikov, E. Prudnikova, V. Konovalov, S. Pasechnik, Z. H. Ling, D. D. Huang, X. Li, P. Xu, G. Hegde, and H. Y. Mak. They have provided much important information and have contributed greatly to our research program. We also owe much to our friends Drs H. Takatsu, H. Takada, H. Hasebe, and M. Schadt for many stimulating discussions.

References

[1] E. D. Kvasnikov, V. M. Kozenkov, and V. A. Barachevskii, Birefringence in polyvinyl cinnamate films, induced by polarized light. *Dokladi Akademii Nauk SSSR* **237**, 633 (1977) (in Russian).

[2] K. Ichimura, Y. Suzuki, T. Seki, A. Hosoki, and K. Aoki, Reversible change in alignment mode of nematic liquid crystals regulated photochemically by 'command surfaces' modified with an azobenzene monolayer. *Langmuir* **4**, 1214 (1988).

[3] W. M. Gibbons, P. J. Shannon, S. T. Sun, and B. J. Swetlin, Surface mediated alignment of nematic liquid crystals with polarized laser light. *Nature* **351**, 49 (1991).

[4] M. Schadt, K. Schmitt, V. Kozenkov, and V. Chigrinov, Surface-induced parallel alignment of liquid crystals by linearly polymerized photopolymers. *Japanese Journal of Applied Physics* **31**, 2155 (1992).

[5] A. G. Dyadyusha, T. Ya. Marusii, Yu. A. Reznikov, A. I. Khizhnyak, and V. Yu. Reshetnyak, Orientational effect due to a change in the anisotropy of the interaction between a liquid crystal and a bounding surface. *JETP Letters* **56**, 17 (1992).

[6] L. M. Blinov, Photoinduced molecular reorientation in polymers, Langmuir Blodgett films and liquid crystals. *Journal of Nonlinear Optical Physics and Materials* **5**, 165 (1996).

[7] M. O'Neill and S. M. Kelly, Photoinduced surface alignment for liquid crystal displays. *Journal of Physics D: Applied Physics* **33**, R67 (2000).

[8] M. Schadt, Liquid crystal displays and novel optical thin films enabled by photoalignment. *Molecular Crystals and Liquid Crystals* **364**, 151 (2001).

[9] V. G. Chigrinov, V. M. Kozenkov, and H.-S. Kwok, New developments in photoaligning and photo-patterning technologies: physics and applications. In *Optical Applications of Liquid Crystals*, Ed. L. Vicari, Institute of Physics Publishing, Bristol and Philadelphia, 201–244 (2003).

[10] V. P. Shibaev, S. A. Kostromin, and S. A. Ivanov, *Polymers as Electrooptical and Photooptical Active Media*, Springer-Verlag, Berlin, 37–110 (1996).

[11] V. Shibaev, A. Bobrovsky, and N. Boiko, Photoactive liquid crystalline polymer systems with light-controllable structure and optical properties. *Progress in Polymer Science* **28**, 729 (2003).

[12] V. Chigrinov, S. Pikin, A. Verevochnikov, V. Kozenkov, M. Khazimullin, J. Ho, D. Huang, and H.-S. Kwok, Diffusion model of photoaligning in azo-dye layers. *Physical Review E* **69**, 061713 (2004).