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Rising in the east: "The Liquid Crystal Display Story", edited by N. Koide

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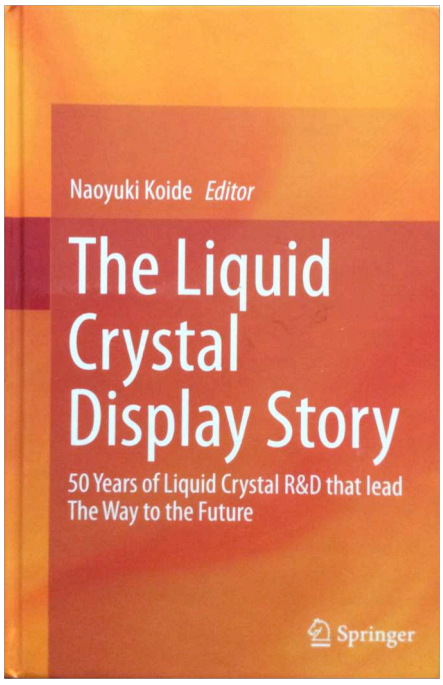
The recently published book "The Liquid Crystal Display Story", edited by N. Koide and published by Springer is an essential addition to anyone interested not only in the history of liquid crystal displays, but also those involved in the future of liquid crystal related research. What sets this volume apart is that it concentrates on the story from a Japanese perspective, giving the reader an insight into the innovation process itself using stories that will be unfamiliar yet fascinating to many readers.

Liquid crystal displays are an enabler for the digital age and are an essential component of mobile communications. Those wishing to understand the history of the subject may turn to the book by Joseph Castellano, *Liquid Gold* [1], one of the original protagonists at RCA where the LCD industry was borne in the 1960s. That book is a fascinating read, because Castellano brings stories and science together with the flourish permitted through personal memories. Those looking for further insight into the Liquid Crystal story and its part in the flat-panel display revolution may then turn to David Dunmur and Tim Sluckin's *Soap, Science, and Flat-screen TVs: a history of liquid crystals* [2], or Cyril Hilsum's review in *Philosophical Transactions* [3]. My personal favourite account of the industry hereto has been Hirohisa Kawamoto's review [4], particularly for its in depth scientific perspective but also for its history taken from a Japanese perspective. After all, although the story of liquid

crystals begins in Europe and the USA, it is the product oriented research and development completed in Japan from the early 1970s to the 2000s that is arguably the most important part of this story. The story of how Tomio Wada led the early research at Sharp to produce the world's first pocket calculator in 1973 is not just about invention, but innovation too. Wada collected a team of twenty scientists and engineers to solve all aspects of the display, from developing room temperature mixtures, display construction and CMOS electronics to release a first product in only two years. It is the quality of this innovation that is so strong throughout Japan: without this Japanese innovation, liquid crystal displays would still be a laboratory curiosity and some long-forgotten patents, rather than the enormous worldwide industry it is today. I have a personal recollection of being introduced to Wada-san during a Sharp collaborative meeting at the Tenri site near Nara in Japan during the mid 1990s. He was acutely aware of the importance of innovation, proudly showing me the factories that surrounded the Research Laboratories; factories that his innovation had helped create.

Yet this is but a small part of the Japanese LCD story, a story that is yet to be told in its entirety. *The Liquid Crystal Display Story: 50 years of Liquid Crystal R&D that lead The Way to the Future*, edited by Naoyuki Koide and published by Springer, is the most complete account of the science and the technology from this period that I have read. This 416 page book is divided into two sections, the first of which describes in detail the history of Japanese LCD innovation, from the initiation of the display development programme at Sharp in 1970 to the various liquid crystal modes that have been used historically, today and predictions for the next generation of displays. Unlike other histories, this one is more complete with detailed descriptions of the research programmes on the various



components required for a modern device: liquid crystal materials, alignment layers, electronic drivers and control circuitry, polarisers, colour filters, optical compensation films and display backlights. Despite the display-centred title of the book, the second section is devoted to a glance to the future of liquid crystals, from the novel materials, phases and physics, to a world of new device possibilities based on liquid crystal semi-conductors, light-driven plastic motors, tuneable photonic materials and pharmaceutical applications.

For the first section, the editor has collected the most impressive list of contributors from this Golden Age of Japanese innovation. Unlike, the names of Heilmeier, Gray, Helfich, Fergason or deGennes, many of these contributors have been relatively anonymous. However, the contributions to both science and technology that the reader is introduced to in Koide's book are the equal of their more celebrated peers. Contributions are included from many technical giants of our field, who made their advances whilst working from within industry: Funada at Sharp was one of the first to join Wada's nascent LC group in 1970 and helped steer the early display work to the AC driven Dynamic Scattering Mode after reading the theoretical treatment of de Gennes; Toriyama and Kawakami at Hitachi defined the driving methods and circuitry for the DSM and TN modes, including the invention of the Amplitude Selection scheme used in passive matrix CMOS drivers; Matsuo and Kuroda at Dai Nippon Print who's early work established polyimides as the *de facto* choice for alignment layers; Ito at Nitto Denko and Yamahara at Sharp (now at Sumitomo) who invented compensation films required for wide-viewing angle LCD; Yoshida and Okamoto of Sharp for their driving roles in the development of multi-domain LCDs and Käläntär of Global Optical Solutions for his work on backlight waveguides. Other authors have more academic origins, but partnered strongly with industry to help enable the technological progress: Ichimura (Agency of Industrial Science and Technology, now at Tokyo Institute of Technology) who, together with DNP's Matsuo created the team that developed the first dispersed pigment colour filters to be commercialised by Dai Nippon Print in the mid 1980s; Kobayashi at Tokyo University of Science in Yamaguchi who developed the world's first rubbing machine in 1971, and developed many alignment layers with Sharp, Nissan Chemical Industries and others. Guest contributor, Martin Schadt provides a welcome review of his outstanding contribution to LCDs. His presence in this volume is warranted not only by his long association with

Japanese display makers but in particular because of his founding of Rodic Ltd. based in Saitama, a joint-venture between Dai Nippon Ink and Chemicals (DIC) and Schadt's native Swiss company Hoffman La Roche.

These early chapters of the book are filled with anecdotes from authors so closely tied to the innovations being made, and as such give great insights into the process of innovating itself. Funada-san describes the importance of timing in bringing together the complex set of inter-related inventions:

- 1959 Jack Kilby's invention of the integrated circuit;
- 1962 Richard William's invention of the LCD;
- 1963 Frank Manon Wanless development of the CMOS transistor;
- 1968 George Heilmeier's invention and prototype of Dynamic Scattering Mode LCD;
- 1969 Hans Kelker's synthesis of the first room temperature liquid crystal;
- 1969 Yoshiyuki Katsube's production of the transparent conductor Indium Tin Oxide films on glass;
- 1970 Pierre de Gennes' theoretical treatment of the effect of ions on dynamic scattering.

However, Fundada also lists the importance of setting the appropriate target for the innovation to succeed. In this case, it was the decision of Sharp to stop work on flat Cathode-Ray Tubes, and to pursue LCD rather than LED, which were considered unsuitable for the newly invented CMOS drivers due to their higher current. In 1999, Sharp set the goal of finally meeting Sarnoff's vision and replacing the Cathode Ray tube for televisual displays with LCD by 2005.

As the reader picks through the historical chapters, many other lessons for the innovator become apparent. The need for tenacity, both from the individual and the management team is essential. It is surprising how often companies gave up on early success, only to be proven misguided by later commercialisation. A clear example is given by Schadt, who points out that Hoffman La Roche dropped liquid crystal work in 1971, soon after the

invention of the twisted nematic display, only to resume once its success became more obvious in 1973.

The importance of vision and judgement is also evident. Nitto Denko were not a polariser manufacturer originally, but saw the need for self-adhesive polarising layers early in the development of LCD. Having solved the problems of applying the adhesive to the delicate polarisers they sourced from other suppliers, they switched to producing their own polarisers to supply the burgeoning market, eventually growing to make reflective polarisers for TN, transmissive polarisers for STN, through to the manufacturing of very large area, high quality polarisers for today's TFT displays. Exploring ones way through a patent minefield may also be a necessary skill. This is evinced by Schadt's account of how Merck had originally restricted some of their early liquid crystal materials to compounds that *were* liquid crystalline. This restriction may seem somewhat of a necessity. However, Schadt explains how mesogenic molecules with end-chains too short to give unequivocal liquid crystal phases are useful as low viscosity components for wide temperature range mixtures, when used as admixtures with longer chain molecules. Schadt's vision to spot this weakness paid dividends to Roche, through a patent licence to Merck for the use of this approach. Japan Synthetic Rubber also displayed such vision. Nishikawa-san describes how the production of a common component used in the petrochemical industry also produced a useless bi-product: cyclopentadiene. Soluble polyimides for liquid crystal alignment layers were one suggestion, and the study conducted to find the most suitable candidate for high thermal stability yielded what became an industry standard: Optomer AL 1051.

In addition to judgement, serendipity also plays its part, of course, and often its role in innovation provides the reader with the most interest. Funada-san remembers accidently leaving the lid-off his nematic phial only to then find that it gave improved AC dynamic scattering mode operation, thereby fuelling a joint development project with DIC to find suitable ionic additives for liquid crystals. I didn't know whether to believe Kuroda-san and Matsuo-san from Dai Nippon Print when they explained that it the dog-racoon that provides the best hair for use as a rubbing clothe material, and indeed how they chose this material to test in the first place. Perhaps it shows just how dedicated the industrial experimentalist must

be in the search for the winning edge. The luck of meeting the right collaborators, often from completely different fields, also plays a role. Urayama-san from the Kyoto Institute of Technology explains how his work on twisted nematic elastomers for use in micro-machines was influenced through a chance meeting with Fangfu Ye, a condensed matter physicist working at the University of Illinois, during the coffee break at an international conference.

Above all, it is clear that innovation is founded on ingenuity. This is something that is apparent in every chapter of the book. It is not just the academic, but the industrial work too that is filled with such creativity. Indeed, it is common for industry to lead academia in science too, due to the brilliance of its researchers combined with the need for confidentiality. Unlike academia, where a seemingly insurmountable problem often induces the researcher to seek a more tractable challenge, the industrial scientist has no choice but to soldier on. For example, Ito-san from Fujifilm describes how difficult it was to achieve both high quality and scale for Wide-viewing angle films. These achievements were founded on retaining expertise within the company and maintaining years of experience of releasing new products. One of the best chapters in the volume is by Yoshida-san and Okamoto-san of Sharp who describe the latest LCD modes for use in displays. These authors get the balance of technology and science just right, and provide an in-depth review of photo-aligned multi-domain modes, including polymer-stabilised alignment (PSA) and Vertical Aligned In-plane field switching. Such is the rapidity with which innovation occurs in the LCD industry that this is one of the first descriptions of these modes to appear in a textbook, despite it being a technology that is commonly found in stores and sitting rooms around the world.

Yoshida-san and Okamoto-san's review ends with a particularly fascinating observation: that big inventions often occurs soon after a manager is transferred into a team from an unrelated area. They argue that invention and innovation are helped by moving to a new environment. I desisted imagining that this may also be helped by foresight from senior management, in redeploying a failing predecessor when an important problem needs to be solved.

Common to many of the authors is their humility. By the very nature of industrial research, one becomes aware of the importance of the team that surrounds you. But here the

respect for co-workers is a testament to the authors and is an additional joy to read. Often a section ends with a polite disclaimer modestly recognising the small part played by the author. Alternatively, the conclusion articulates admiration for the contributions of others, apologises for the personal nature of the views being given, or expresses hope for the future of the field. An excellent example of how the reader can be captivated by the personal views of an esteemed scientific teacher is given by Takezoe-san from the Tokyo Institute of Technology. With his detailed report of the various tilted smectic phases he is gracious in the credit he pays to Yves Galerne for his role in the discovery of anti-ferroelectric liquid crystals. Takezoe-san is justly worried about needless, and occasionally unpleasant, changes of nomenclature that often lead to confusion and disruption to a subject. Most importantly, he lends his advise to young scientists starting their journey: don't be presumptuous; keep your mind open to the possible; "when you find an unexplained phenomenon, do not think of it as some mistake. Please have in mind that there is the possibility that this uncommon phenomenon may lead to a big discovery". Good advice, indeed, and not just for the young.

Whilst the Editor has done a noteworthy job in gathering together many of the key protagonists of the LCD story, and many of the best Japanese researchers to study the comprehensive science of the subject, other aspects of the editing are somewhat weaker. The appearance of repeated sentences (p103), out of sequence referencing (p327) and repeated references often in close proximity (ref 6.44 and 6.46) may distract the reader from the story. One rather curious mistake is made by Schadt, who mis-names the rather famous Frank Leslie as Eric Leslie, presumably because of his name being synonymous with Leslie-Erickson theory. Some of the chapters are weaker than others, and some written in a rather dry way, devoid of the interesting stories that enrich so many of the rest. But all of these are small problems that are to be expected in a book as diverse as this. However, I did feel that the book started poorly, with a history of the 142nd *Committee of the Japanese Society for the Promotion of Science, on Organic Materials used in Information Science and Industry*. This committee was established in 1974 and has been renewed every 5 years since then, helping steer the progress made in the Japanese industry. Although this is a worthy chapter for the book, it gives little context to the great work that follows. I would prefer to see an overview of the history of Japanese LCD Science and Innovation, the universities and companies

involved, and the key players in those institutions. Historical sequence is naturally lost by the structure demanded by a subject in which experts described the major breakthroughs for particular device functions. However, this makes the need for a suitable overview all the more important. Also, it is difficult to follow which companies the authors were working for during their historical contributions. Arguably, it is particularly important to recognise the companies responsible for achievements, since often the work is published only in patents, and the names of team members for some of the biggest contributions to the technology only too anonymous. Occasionally, authors have joined new companies and so the readers are left trying to decipher some of the history for themselves. Neither is there an index, so those readers using the work as a reference will find it harder to use.

Also, there are many technologies that are not included in this book that would have given extra insights into the innovation process. From my own experiences, I missed reviews from the mammoth and near successful projects done on Ferroelectric Liquid Crystals, particularly by Canon and Sharp, and the work done on bistable nematic LCD, including that by Seiko Epson on the Bistable Twisted Nematic Mode. There must be similar stories for the various components that make up an LCD. It would be interesting to read about what makes a technology fail; whether it is a lack of tenacity, vision or ingenuity, plain bad luck, or whether some technical hurdles are just too difficult to overcome. Perhaps, it is as Churchill explained, that history is always written by the victor.

These complaints are small, and should in no way detract from the enjoyment and utility of a fabulous book. It is merely that the quality of the story being told demands the highest quality of presentation, and perhaps some of these misdemeanours may be corrected in a second edition that the subject matter so richly deserves.

The book ends with a list of the major scientific breakthroughs and product launches in liquid crystals and LCD, written a few years ago at Kent State University and Kent Display Inc. Thirty five of the sixty-four product inventions and twenty-seven of the seventy-seven scientific breakthroughs are Japanese. This alone is an outstanding testament to the world-wide contribution from this nation of innovators. Yet, as I completed reading the book, I was struck by the question of whether the trillions of yen dedicated to the research and

development that enabled this whole industry to become a success has actually been worth it, for Japan and its industry. Like you I am surrounded by the successful outcome of these pioneers and the positive impact they have made to society. But I am also aware of the struggles being had by those companies with ever diminishing near-zero profit margins, after years of high investment in R&D and IPR. Perhaps these bright and young minds responsible for looking to the future of the technology will find new ways of winning commercially, as well as hope in the seemingly immeasurable possibilities offered by this most fascinating variety of materials.

1 J. A. Castellano (2005) *Liquid Gold: The Story of Liquid Crystal Displays and the Creation of an Industry*, World Scientific Publishing Co. Pte. Ltd., ISBN 981-238-956-3.

2 D.A. Dunmur and T.J. Sluckin (2011) *Soap, Science, and Flat-screen TVs: a history of liquid crystals,* Oxford University Press, New York.

3 C. Hilsum (2010) Flat-panel electronic displays: a triumph of physics, chemistry and engineering. *Philosophical Transactions. Series A, Mathematical, Physical, and Engineering Sciences*, *368*(1914), 1027–1082. http://doi.org/10.1098/rsta.2009.0247

4 H. Kawamoto (2006) *The History of Liquid-Crystal Displays*, Proceedings of the IEEE, **90** (4), 460–500.