HANDBOOK OF DISPLAY TECHNOLOGY

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1.2.4 VACUUM FLUORESCENT DISPLAY (VFD)

The first vacuum fluorescent displays (VFDs) were single-digit display tubes developed by Dr. T. Nakamura of Ise Electronics Corporation in 1967.[20] The technology offered a means to provide a flat, thin CRT-like display that could be operated at much lower voltage. These tubes used a ceramic anode substrate that was sealed in a glass bulb. Later, NEC Corporation and Futaba Corporation became major suppliers of VFDs. The early VFDs were used in calculators and were made in increasingly smaller sizes as the calculators decreased in size. The next generation tubes were the multidigit displays, again made with a ceramic substrate, but with multiple digits 10 or 12 mm high. The third-generation tube, introduced by Futaba Corporation, displayed multiple digits but was made with less expensive glass. Today, Futaba holds the largest share of the worldwide market with NEC a strong second and Ise third. Samsung Electron Devices (Suwon, Korea) makes VFDs mainly for use in the firm's microwave ovens and VCRs.

In addition to the desire to produce a flat, thin light emitting display that could be operated at low voltage, another reason the VFD was developed was a rather practical one. By the mid-1960s, vacuum tube production had become a high-volume, automated process. Unfortunately, by this time vacuum tubes were rapidly being replaced by solid-state components. The VFD was seen as a new product that could be made with old but cost-effective equipment. Hence, this development was driven, in part at least, by a need to convert a factory from the production of one type of component to another. The message here is that sometimes it is not necessary to shut down a plant and lay off all the workers if one can be creative about using the plant for another purpose.

1.2.5 LIQUID CRYSTAL DISPLAY (LCD)

Although liquid crystallinity was first observed in 1888 by Reinitzer, it was more than 30 years before Mauguin[21] discovered and described the twisted-nematic structure that later became the basis for liquid crystal display (LCD) technology. During the 1920s and 1930s work on liquid crystal materials and the electro-optic effects that they produced was conducted in France, Germany, the U.S.S.R., and Great Britain. Perhaps the first patent on a light valve device that used liquid crystals was awarded to the Marconi Wireless Telegraph company (now part of GEC) in 1936.[22] Then in the mid-1950s, researchers at the Westinghouse Research Laboratories discovered that cholesteric liquid crystals could be used as temperature sensors. It was not until the 1960s, however, that serious studies of the materials and the effects of electric fields on them were carried out. One reason for this was that liquid crystals were little known materials and, in fact, the first book in English to treat the subject was not published until

Dr. George W. Gray's "Molecular Structure and the Properties of Liquid Crystals" appeared in 1962.[23] This excellent book quickly became the definitive work on the subject. Before its publication, students of organic chemistry in most U.S. universities did not know what a liquid crystal was!

The early work on applications of liquid crystals was carried out in research laboratories in the United States, Europe, and Japan. During this period, a great deal of research and development was performed; theories were formulated and tested, a number of electro-optic effects were discovered, materials with broader operating temperature ranges were prepared, and rudimentary fabrication techniques were developed.

The idea of using liquid crystal materials for display applications was probably first conceived in 1963 by Drs. Richard Williams and George Heilmeier at the David Sarnoff Research Center (then the central research arm of RCA Corporation) in Princeton, New Jersey.[24] Later, a larger group, headed by Heilmeier and including Louis Zanoni, Joel Goldmacher, Lucian Barton, and the author, spearheaded the work to develop liquid crystal displays for application to the fabled "TV-on-a-wall" concept, a dream of the late TV pioneer David Sarnoff. During the period from 1964 to 1968, this group discovered many of the effects that were later to be commercialized, including dynamic scattering,[25] dichroic dye LCDs,[26] and phase-change displays.[27] One of the major breakthroughs occurred in the summer of 1965 when it was discovered that by mixing various pure nematic liquid crystalline compounds together it was possible, for the first time, to produce stable, homogeneous liquid crystal solutions that could operate over a broad temperature range including ordinary room temperature.[28] Later, cyanobiphenyl materials with improved properties and even broader temperature ranges were developed;[29] these compounds form the basis of most of the liquid crystal materials used today in commercial products.

During the mid-1960s, work on liquid crystal displays was also being performed by A. Kapustin and L. S. Larinova in the Soviet Union[30] and by George Elliott and J. G. Gibson at Marconi Electric in England.[31] Later, a group that included Joseph Wysocki, James Adams, and Werner Haas at Xerox also carried out extensive liquid crystal display research.[32]

By 1969, it became clear to the RCA group and others that the development of large-screen, LCD television sets would require "many years of research," although nobody believed it would take 16 years. Thus, an effort was mounted to develop simpler display devices that could be commercialized quickly. One of these was the "point-of-purchase" display, a moving advertisement display used in retail stores. These segmented displays (produced by RCA and Ashley-Butler in the early 1970s) were made in sizes up to 12 × 12 inches. The system used a rotating copper drum patterned in such a way as to send electrical signals to the appropriate segments of the display at the proper time to create the desired motion. Although this application proved to provide a very limited market, many of the techniques developed for production of these large-size LCDs were later used for the manufacture of smaller displays.

Among the most important early applications were the wrist watch and portable calculator, made possible by the low power consumption of LCDs and the integrated circuit industry, then in its infancy. Some of the "products of the future" envisioned in papers published in the 1969–1971 period were numeric indicators for instruments, digital clocks, digital wrist watches, optically tuned color filters using the so-called "guest-host" effect, electronically controlled "window-shades," and "displays for auto dashboards, aircraft cockpits, scoreboards, highway signs, and computers." Today, we see LCDs in virtually all of these applications.

One of the most important major breakthroughs occurred in late 1969 when James L. Fergason, working at a newly formed firm, International Liquid Crystal Company (ILIXCO) in Kent, Ohio, discovered the twisted-nematic (TN) field-effect LCD, which ultimately proved to be the most successful for the watch, calculator, and later, other applications including TV. Because Mr. Fergason's patent application was not made public until several years later,[33] Drs. Wolfgang Helfrich and Martin Schadt of F. Hoffmann LaRoche in Basel, Switzerland, published a paper on the same effect in 1971[34] and were awarded a patent in 1975.[35] Needless to say, this sparked a long legal battle over ownership of the invention. Eventually, the issue was settled out of court. That Mr. Fergason is generally regarded as the inventor of the TN-LCD is exemplified by the fact that he was awarded the highest honor of the Society for Information Display for his initial discovery.

Between 1970 and 1972 activity in the LCD field increased enormously and many companies in the United States, Europe, and Japan began to exploit the development of the 1960s. The coincident development of large-scale integrated circuits for driving and timekeeping functions resulted in the development of the LCD wrist watch and calculator. The early 1970s also saw a number of new American companies formed to exploit LCD technology. Among these were ILIXCO, Optel Corporation and Princeton Materials Science (Princeton, New Jersey), Microma (Cupertino, California), Micro Display Systems (Dallas), and Integrated Display Systems (Montgomeryville, Pennsylvania). All of these firms set out to manufacture LCDs and the digital watches that used them.

In those early days, it was American engineers and scientists who developed the first processes for the fabrication of LCDs and digital watches. It was an exciting but sometimes frustrating time because the technology was in its infancy and engineers were forced to work with equipment that was adapted from other industries. Although the equipment used was crude by today's standards, the same fundamental techniques are now being used to manufacture the hundreds of millions of LCDs made each year throughout the world.

During these early years, many Japanese firms followed and copied the developments coming out of the United States. However, they quickly began striking out on their own by developing improved fabrication and packaging techniques that resulted in greater reliability and lower manu-

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