NONEMISSIVE ELECTROOPTIC DISPLAYS

Edited by
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FOREWORD

Shortly after the inception of the Brown Boveri Research Center in 1966, plans were made to organize a series of biennial scientific symposia. A different subject was to be chosen for each symposium with the following requirements in mind:

- It should characterize a part of a scientific discipline; in other words, it should describe an area of scholarly study and research.
- It should be of current interest in the sense that important results have recently been obtained and considerable research effort is under way in the world's scientific community. In other words, there must be a good reason why the symposium should be held now, rather than five years earlier or five years later.
- It should bear some relation to the scientific and technological activity of Brown Boveri.

These symposia are intimately related to one of the basic concepts which govern the work of our Research Center: Close coupling between science and engineering. It is to this coupling that we owe the technical standard of our products and it is this coupling which we hope will be furthered by our symposia.

It is often said that the important technological innovations come from the basic sciences, and the transistor is taken as a brilliant example. Indeed, the transistor is based on quantum mechanics, a thoroughly fundamental scientific structure which in turn predicts the behavior of electrons in a crystal lattice and explains the existence of energy bands. Without knowledge of quantum mechanics, the invention of the transistor would have been impossible. This is a model case for the following sequence of events: first, scientific discovery; then, engineering invention.

It is good to note that this course, although frequent, is not the only path along which technological progress takes place. In fact, the opposite sequence is quite common: first, engineering invention; then, discovery of the underlying principles. Fluid dynamics, the subject of the first Brown Boveri symposium which took place six years ago, is almost a model for this process. The first steam turbines were designed and successfully built by

people who were only vaguely acquainted with the scientific laws underlying their machines, and, in fact, some of these laws were not even known at the time. The fundamental concept of entropy was just being introduced into the engineers' language, and much time elapsed before turbine designers were willing to adopt this concept in their daily work. The fact that these men were able to design very satisfactory turbines of 10 000 kilowatts in this manner is an impressive illustration of their deep intuitive insight.

For further progress however, science was essential. Giant turbogenerators each having a rating of 1300 Megawatts are now probably the best known among our products. The inventor still plays a key part in the design process; but he must interact closely with the scientist, and he must frequently ask himself: "How far from the optimum is my invention? Am I expecting something that is against the fundamental laws of nature? If not, what can be ultimately achieved with my idea?" Without the answer to these questions, technical progress would be impossible beyond a certain point, and this, of course, holds not only for turbines, but for all fields of technology.

Non-emissive displays exemplify a third course of development intermediate between the two foregoing cases. As little as five years ago, liquid crystal displays were little more than a laboratory curiosity; today watches and calculators with such displays can be bought in stores almost throughout the world. One can hardly find a better example to demonstrate how progress can come about through the intimate coupling of science and technology — or, to put it somewhat differently — through the simultaneous application of insight gained through scientific analysis and knowledge obtained empirically.

The Brown Boveri interest in this field can be traced to 1969 when BBC and Hoffmann-La Roche joined their R&D forces in an attempt to enter the field of biomedical engineering. This joint program produced a large number of exciting results, the best known of which was the discovery of the electro-optic properties of twisted nematic liquid crystal structures (the Schadt/Helfrich Effect). After termination of the partnership, a research program in the field of liquid crystal displays was continued and expanded at our Research Center. Two years ago Brown Boveri decided to enter the field of optoelectronic components when it started setting up a manufacturing plant for liquid crystal displays. Needless to say the R&D effort has been further intensified after the decision for large scale production of liquid crystal displays was reached. The result of this decision has been a very strong commitment to the field of non-emissive displays, because we believe in their future and in the market opportunities opened by the various technologies described in these Proceedings.

Since the establishment of the Brown Boveri Research Center, research programs were started in most of the fields of the commercial activity of Brown Boveri, including all three of our examples: semiconductor devices, steam turbines and non-emissive displays. In the course of the years we were surprised to find out how closely related these seemingly widely different

areas become if one moves toward the scientific end. We see one of the great challenges of today's industrial research in the task of looking for unanswered questions in widely different fields of technology and of seeking common answers in the sciences. This is only made possible by the organizational concept of corporate research which we have adopted, and of which these symposia are a manifestation.

The 1975 symposium on Non-Emissive Electrooptic Displays was attended by 96 participants from 6 European countries, the United States and Japan. It was both an honor and a pleasure to welcome scientists and engineers from so many parts of the world. Their willingness to travel to Baden and to spend two full days with us was a challenge as well as an obligation to us as organizers, and we sincerely hope that by the end of the meeting the expectations which prompted them to attend were fully met.

We should like to express our gratitude to all authors, who undertook the laborious task of preparing and delivering papers, and also to the discussion speakers, who contributed significantly to the success of the meeting.

To conclude, we should like to express our gratitude to every participant in the symposium. Special thanks are addressed to Drs. F. K. von Willisen, A. R. Kmetz and J. Nehring, who were responsible for the scientific part of the symposium, and also to Mr. E. Arn and Mrs. U. Richter for organizing and handling the administrative side of the meeting.

Owing to the limited space available and the desire to avoid an unwieldily large congress, it was not possible to extend invitations to a larger circle. With much regret, we had to disappoint a number of applicants who wished to participate. We hope that the present publication may be a partial compensation for those whom we did not have the pleasure of welcoming as our guest.

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PREFACE

Recent advances in microelectronics have greatly stimulated research and development on a new class of electrooptic displays which themselves emit no light and which therefore offer low-power, low-voltage operation. The technology of these non-emissive displays is a new field, growing rapidly in divergent directions. Researchers in this field who specialize in one of the many physical effects find it increasingly difficult to keep track of the nature and significance of developments in other areas and to maintain a realistic perspective on the relative importance of various aspects of their own work. Likewise reports of new developments, written for an audience of specialists, seldom fit the needs of potential users of non-emissive displays, who seek to evaluate and compare the various competing technologies with regard to a specific application. The evident need for a detailed technical overview of the non-emissive displays field from the viewpoint of application to practical display systems is the motivation for this book, and for the symposium out of which it grew.

Having determined to devote the fourth Brown Boveri Symposium to "Non-Emissive Electrooptic Displays", a program of topics was selected to cover the materials, phenomena and technology of this broad field. Leading scientists were then invited to prepare and present extensive review papers on these topics. Relevance to display applications was an explicit goal, and comparisons among various approaches were encouraged. The invited reviews were to be supplemented by short contributed papers and by technical discussions moderated by knowledgeable session chairmen.

The symposium took place on September 29 and 30, 1975 at the Brown Boveri Research Center in Baden, Switzerland. The entire first day was devoted to liquid crystals, reflecting their present dominance of non-emissive displays. Since the physics of the twisted nematic device is now well established, D. W. Berreman was able to use computer calculations to demonstrate the dependence of electrooptic performance on material and fabrication parameters. The principal display effects in cholesterics were reviewed by E. P. Raynes, and potentially major improvements from pleochroic dyes and hysteresis effects were cited. T. J. Scheffer presented a broad and rigorous survey of liquid crystal techniques for color displays. Relationships between

molecular structure and display performance were discussed by D. Demus. Surface alignment techniques, including a method for weak anchoring, were reviewed by E. Guyon, who reported recent progress toward quantitative understanding of boundary effects.

The first three papers on the second day dealt with electrochromism. H. R. Zeller derived from basic principles some reasonable expectations for ultimate display performance. In surveying the possible materials and effects, I. F. Chang distinguished between electronic and electrochemical processes, finding the latter category much more promising for displays. Practical details of cell fabrication and driving methods were discussed by J. Bruinink. Later, material problems were identified by J. C. Lewis as the main obstacle to realizing the impressive potential of electrophoretic displays, and slim-loop PLZT emerged as the most promising candidate for a ferroelectric display in K. H. Härdtl's review. The symposium closed with a session on addressing techniques for non-emissive flat-panel displays. The compromises between optical performance and electrical complexity which limit matrix addressing of the various display effects were described and compared by A. R. Kmetz. Techniques for circumventing these limits by integrating electronic components into the display panel were reviewed by T. P. Brody, who reported striking progress with thin-film transistor arrays.

This book contains all invited review papers, as well as several short contributed papers, which were presented at the symposium. In addition the keynote paper by J. Kirton and concluding remarks by C. Hilsum provide useful information, as well as some stimulating opinions, concerning displays from a more general perspective. Discussion remarks, selected from written notes and tape recordings, are also included.

It is our pleasure to acknowledge the most gratifying cooperation of all authors with our editorial attempts to impose consistency of style and format on contributions from diverse scientific disciplines and nationalities. We are grateful for their responsive and considered support which made the timely completion of this book possible. We also acknowledge the indispensable efforts of Mrs. U. Richter who typed the entire camera-ready manuscript.

Baden, March 1976 A. R. Kmetz F. K. von Willisen

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