ACOUSTO-OPTIC DEVICES AND THEIR DEFENCE APPLICATIONS

JC Joshi

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PREFACE

Ever since I started working in the field of acousto-optics (AO), I faced difficulties almost at every step in the development of devices such as AO deflector or modulator. Indeed, libraries are well-stocked with books explaining the complex theories of the subject. As a result there was little or no information available which provide practical steps or tips for application of the theory in device development. This prompted and motivated me to write a book that not only explains theoretical aspects but also devotes sufficient pages outlining the practical steps required in developing AO devices. This book has been written keeping in mind the requirements of a new worker in the field of AO and includes some practical tips useful in device development, which are scattered in the literature in the form of scientific papers published in various journals. I do hope that both researchers and students of acousto-optics would find this book useful, to some extent if not fully, in pursuing their interest in the area of AO work.

I have devoted the first two chapters to the theories of the AO. These theories have been written to highlight the basic underlying principles of AO in a way simple and easy to understand. The third chapter deals with the designing of AO devices. To make things simple and easier, only three types of devices namely, AO deflectors, modulators, and AO tunable filters have been chosen.

The fourth chapter is devoted to the fabrication techniques and procedures for these devices. Since testing and evaluation of devices is considered to be the part of device fabrication, the second half of fourth chapter has been devoted to this aspect. In the original proposal for writing this book the contents of the fifth chapter were not planned. After writing the first four chapters it was felt that the present work will not be complete if the topic of integrated AO is not included, for the simple reason that this technique is going to dominate largely if not fully, the future development of AO. Thus the fifth chapter has been devoted to encompass

the theory and designing the AO devices in the integrated optic version. As I have been associated with defence related research, the sixth chapter discusses the applications of the AO devices in the field of defence. At the end a small seventh chapter has been added to present the futuristic trends in this field.

The present project could not have been completed successfully without the financial help provided by the Defence Research and Development Organisation for which I am highly indebted to the Organisation. I am highly grateful to my friend Amitav Mullik, Former Director, LASTEC for helping me in arranging the financial help from DRDO. I also acknowledge the University of Colorado, Colorado Springs, USA for allowing me to briefly access their library. My sincere thanks are due to my friend and associate Dr AL Dawar, who helped me in forming the plan of this project. Lastly I thank my wife Gayatri who always tirelessly inspired and encouraged me during the entire period of this project.

Delhi JC Joshi

April 2007

CHAPTER 1

LIGHT PROPAGATION IN A TRANSPARENT MEDIUM

1.1 INTRODUCTION

Acousto-optic (AO) interaction has been developed during the last forty years of the 20th century. It will be interesting to see the historical background which gave birth to the development of this most powerful technique in the field of optical signal processing. Optics and acoustic waves were studied independently since the early 19th century. The acoustic waves and their propagation through different materials—metallic/non-metallic, transparent or opaque, were studied in detail by Rayleigh[1] who specially described an altogether different acoustic wave namely the surface acoustic wave (SAW) in 1880s when he was studying the causes and movement of earthquakes[1]. In 1922, Brillouin[2] predicted that light can be diffracted in a single order by an acoustic wave propagating in a transparent medium, like x-rays from the crystal planes. This prediction, however, could not be verified experimentally until 1932 when Debye and Sears[3] demonstrated light diffraction by high-frequency sound waves, into several orders spread symmetrically on both sides of undiffracted light. In the same year, this phenomena was also demonstrated independently by Lucas and Biquard[4]. The explanation for this multiple-order appearance, instead of a single order contrary to his prediction, was proposed by Brillouin[2]. He proposed that this could be due to rescattering of light by sound waves. During 1935-36, Raman and Nath[5] published a number of papers on the scattering of light by sound waves. A mathematical analysis of the phenomenon was presented based on the proposition that when sound travels in a transparent column, it forms a phased grating which diffracts light into several orders, as is done by a transmission grating. Raman and Nath[5] also studied the effect of incident light at different angles with respect to the direction of an acoustic beam. This was also studied independently by Debye and Sears[3], and Lucas and Biquard[4]. They evolved conditions for diffraction of light into single order and in

multiple orders. In 1965, Klein and Cook[6] presented a detailed qualitative description of single and multiple order diffractions. In 1967, the same scientists[7] presented their work based on a very important parameter known as *Q*-parameter, whose value decides though not very precisely, the regime of diffraction as Raman-Nath or Bragg.

During 1960s, various workers presented different mathematical analyses which included diffraction of light by sound and the frequency modulation of the diffracted light by the frequency of the acoustic waves. With the development of laser, doors of a new era opened in the field of AO interaction and its possible applications. The first account of application of AO interaction was given by Lieben[8]. Later, many other applications of this effect like parallel processing of a signal, television display, and other signal processing were reported[9-11].

As a consequence of AO interaction, two phenomena are generated, i.e., deflection and modulation of light which either singly or in combination have been used in the development of various AO devices. Beam deflectors were studied widely in the mid-1960's. In these studies, it was first noted that the time bandwidth product of an AO device is an important parameter which decides the angular resolution of the device. Search for newer materials for the AO devices started during this decade. By the end of 1960's, with the availability of newer materials with more attractive properties for the development of AO devices and, photolithographically developed transducers for SAW design, AO interaction became a powerful tool for signal processing. Specially, diffraction of single order has become increasingly important for optical signal processing applications.

New theoretical results were pouring in continuously. A generalised coupled-wave mode theory was proposed for arbitrary sound and light interactions[12]. The Raman-Nath theory was extended to the important case of Gaussian sound field[13]. Another important constant indicating the suitability of material as well as M_2, the figure of merit was also introduced during this time[14].

So far, all the work was confined to the area of transparent isotropic materials only. In 1967, Dixon[15] in an important paper theoretically discussed the diffraction of light by acoustic waves in anisotropic crystals / materials. It was shown that for anisotropic materials, the diffraction efficiency is dependent on both the polarisation of incident light and the acoustic waves.

Recent advances in AO materials have made it possible to fabricate multichannel AO devices with a wide bandwidth and large dynamic range. Such devices have a important role in the area of optical matrix processing.

About the Author

The author possesses an M.Sc Degree in physics and a doctorate degree in Quantum Chemistry. He joined DRDO in November 1970. Since then, he worked in various projects like development of transversely excited atmospheric pressure CO_2 laser, pyroelectric detector, surface acoustic wave device, and finally on the development of acousto-optic devices. He worked on the acousto-optic devices for over 17 years and developed several acousto-optic devices both in the bulk acoustic as well as in surface acoustic integrated optic version. After his retirement in 1997, he worked as consultant for two years in DRDO on the development of chemical oxygen iodine laser. He has published 23 papers in various international journals.

About the Book

The book is a balanced presentation of theory, fabrication and characterization techniques and application of the acousto-optic devices. It is written with a view to help a beginner who wants to enter in this field, but does not know where to start and search in the vast available literature. Without going into tedious mathematics, the author has tried to make aware the underlying principles of topics like convolvers and correlators. From the applications point of view, applications of these devices have been given in detail which have direct relevance with the defence equipment technology.

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