FIBER OPTIC SENSORS BASED ON PLASMONICS

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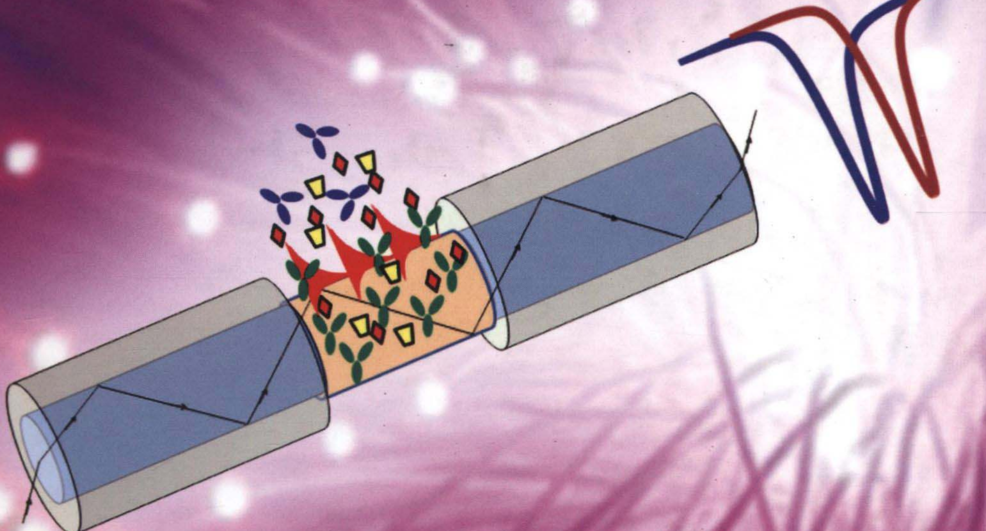

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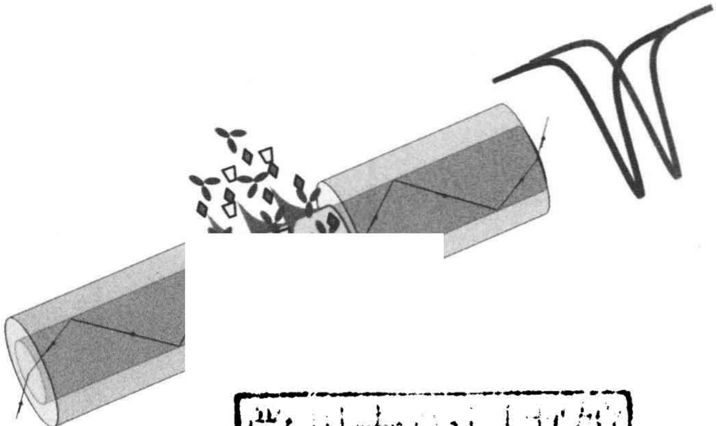

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Preface

This book is an effort of bringing a comprehensive book on fiber optic plasmonic sensors for undergraduate and graduate students. The idea resulted due to many enquiries to one of the authors, Banshi D. Gupta, for writing a text book on the subject. Though tremendous amount of literature is available on the research, hardly any text book is available on the subject. Few books have been edited on surface plasmon resonance (SPR)-based sensors, though, to present the advancement of research to the established researchers.

SPR is a phenomenon that can be dealt with a little primary knowledge of electromagnetic theory and hence can be introduced to undergraduate students with its possible applications. A book by Professor Stefan Meir successfully does a part of the job. However, when it comes to the fascinating world of the sensors and their integration with optical fiber, most of the available literature fails to provide a comprehensive collective knowledge of the subject. With this book, we aim to introduce the undergraduate students and early researchers to an overview of the fiber optic sensors based on the fascinating field of plasmonics, their working principles, and applications. The book helps the established researchers with an insight of the current trends in the fiber optic plasmonic sensors.

In the first chapter of the book we have provided a historical overview of the fiber optic sensors based on plasmonics. A chronological development has been presented, along with the remarks at crucial stages of the development. Further, to build the foundation, the Physics of surface plasmons has been discussed in Chapter 2. The chapter comprises of a rigorous discussion and derivation of the wave-vector condition for surface plasmons from Maxwell's equations, issues related to the excitation of surface plasmons, various techniques of excitation, interrogation techniques, and SPR configurations. In the third chapter, we have presented a detailed description of the various components of a sensor, their characteristics, and roles in the sensor. The important characteristics of sensors have also been discussed. In chapter 4, we have presented a rigorous theoretical treatment of fiber optic SPR sensors. This chapter discusses how to incorporate various light launching conditions in optical fiber sensing. Chapter 5 discusses various methods of fabrication of fiber optic SPR sensors. It presents various surface functionalization strategies depending upon the analyte and the medium/ambience of interest. In Chapter 6, we present a number of studies on SPR-based fiber optic sensor using various surface immobilization techniques. Chapter 7 discusses the effect of some of the intrinsic and extrinsic factors, such as temperature, ions, dopants, etc. on the performance of fiber optic SPR sensors. In Chapter 8, we present an overview of the future trend of research and development in the field of fiber optic SPR sensors. We have added two appendices at the end of the book to provide the treatment of the dielectric functions of the metals and tabulated data of various constants and Sellmeier coefficients.

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I consider myself very fortunate to have worked with Dr. Chandra Deep Singh, Professor Sunil Khijwania and Dr. Navneet K. Sharma on fiber optic evanescent field absorption sensors. My continuous interaction with them has certainly made me wiser in the field of fiber optic sensors. It was this interaction that resulted in the publication of my first book entitled "Fiber optic sensors: Principles and applications (2006). In 2004, I took initiation to work on fiber optic sensors utilizing surface plasmon resonance technique. The research carried out on this topic resulted in 8 Ph.D. theses. I thank Drs. Anuj K. Sharma, Rajan Jha, Rajneesh K. Verma, Sarika Singh, Priya Bhatia, and Satyendra K. Mishra, in addition to Drs. Sachin K. Srivastava and Roli Verma (the other authors of this book), who have worked with me in this exciting field. I learnt a lot from these colleagues through interaction. Indeed, a part of the book has emerged from the work carried out with them. I also thank my present graduate students Rana Tabassum, Anand Mohan Shrivastav and Sruthi Prasood U, for helping me in the preparation of the book. Finally, my special thanks to my wife Uma Gupta for her patience and understanding.

Banshi D. Gupta

Contents

Chapter 1

Introduction

1.1 Surface Plasmons: Historical Perspective

The first observation of the phenomenon of surface plasmon resonance (SPR) dates back to 1902, when Wood[1] reported the "*uneven distribution of light in a diffraction grating spectrum*" while he observed patterns of unusual dark and bright bands in the light reflected from a metal backed diffraction grating. Although, he speculated the possible interaction of the grating-metal arrangement with the incident light, no obvious and clear reason for the observed phenomenon was provided.

The first theoretical description of these anomalies was provided by Lord Rayleigh[2] in 1907, when he published the *dynamical theory of gratings.* He assumed that the scattered electromagnetic field can be expanded in terms of outgoing waves only and predicted singularities in the scattered field at several wavelengths. He could predict that these wavelengths (called Rayleigh wavelengths after his name) resemble the Wood's anomalies and occurred only when the electric field was polarized perpendicular to the grating rulings. He called it *s-anomalies.* His theory predicted no singularities for *p-polarization.* However, the existence of *p-anomalies* was reported by Wood in his later observations and further confirmed by Palmer[3,4] when he found the existence of *p-anomalies* in deeply ruled gratings.

Around the same time, in 1907, Zenneck theoretically formulated a special surface wave solution to the Maxwell's equation and demonstrated that the radio frequency surface electromagnetic waves occur at the boundary of two media when one medium is either lossy dielectric or a metal and the other is loss free.[5] He also suggested that the lossy part of the dielectric constant is responsible for the binding of the electromagnetic waves to the interface. Sommerfeld, in 1909, formulated that the field amplitudes of the surface waves postulated by Zenneck, vary inversely as the square root of the distance from the source dipole.[6] In 1941, Fano theoretically concluded that the anomalies reported by Wood[1] in the diffraction grating spectra were observed due to the excitation of surface waves on the interface.[7] Ritchie, in 1957, for the first time coined the word 'surface plasmons' while explaining the characteristic losses of energy experienced by fast electrons when they travel through thin metal films and demonstrated theoretically that the surface plasmons could be excited on the surface of a thin metal film.[8] In 1959, Turbadar reported that illumination of thin metal films on a substrate leads to a large drop in the reflectivity at certain conditions, but this observation was not linked to the excitation of surface plasmons.[9] In 1960, the excitation of surface plasmons at the metal surface was observed by Powell and Swan.[10] They used accelerated electrons for the excitation of surface plasmons. Soon after, in 1960, Stern and Ferrell showed that the electromagnetic waves at the metallic surface involved electromagnetic radiation coupled to the surface plasmons.[11] In 1968, Otto explained the results obtained by Turbadar[9] and demonstrated that in attenuated total internal reflection, the drop in the reflectivity occurred due to the excitation of surface plasmons.[12] Although the first experimental observation of surface plasmons was observed in 1959 by Turbadar, a clear experimental understanding of the phenomenon was presented only in 1968 by Otto.[12] In Otto configuration (discussed briefly in the next section), a small gap of a few nanometers is to be maintained between a prism base and the metal layer, and the dielectric medium is sandwiched between the prism base and the metal layer. The metal layer is coated on a glass substrate. The Otto configuration