Thin Films and Their Applications in Military and Civil Sectors

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Preface

A thin film is a layer of material ranging from fractions of a nanometer to several micrometers in thickness. Thin films have very interesting properties that are quite different from those of the bulk materials which they are made of. This is because of the fact that their properties depend on a number of interrelated parameters, and also on the technique employed for their fabrication.

Surface quality and material of the substrate, degree of vacuum inside the coating chamber, flow of the reactive gases in the chamber during the growth process, the rate of evapouration/sputtering and the purity of the coating material are some of the important parameters that determine the mechanical, optical and other properties of the coated components. Some of the problems associated with the fabrication of these coatings, and the suitable fabrication techniques have been briefly described in the monograph. Thin films possess a wide range of applications in both civil as well as military sectors. This includes their use for protection of materials from corrosion, oxidation, and wear, increasing transmission or reflection in a certain wavelength region, and also in filters, colour separation, fire-resistance, high temperature superconductors, silicon devices, anti-fog, and memory devices. Their applications in the military and civil sectors are also discussed in the monograph. Applications have been classified into scientific, industrial, consumer, and military applications. The use of thin film catalysts in nanotechnology such as sensors, miniature fuel cells, printable solar cells, MEMS and other IC manufacturing industries, has been highlighted. Some novel applications of thin films in the areas of efficient solar energy conversion, hydrogen conversion and CO_2 conversion to hydrocarbon fuels, bioactive and biocompatible coatings, nanostructures and nano-material coatings, and coatings useful for protection from a wide range of high temperature effects are the emerging areas. A brief description of the future challenges in the fabrication of thin films for such applications in the various emerging fields has been included in the monograph.

This monograph is intended to provide an overview of the design, development of thin films and their coatings for various applications. The book comprises of ten chapters. The first chapter covers types of thin films, thin films design, thin films fabrication, and thickness control. Chapter two provides an overview of metallic films and dielectric coatings with a brief on coatings developed at LASTEC. Chapter three highlights the design parameters, design criteria, and critical issues involving absorption for withstanding high power densities. In Chapter four, various deposition techniques such as electron beam deposition, and sputtering are discussed. Chapter five presents an overview on characterisation tools and equipment. Chapter six provides

detailed scientific applications of thin films like solar cells, Fullerene 60, electronics, silicide thin films, surgery, nanotechnology, etc. Electronic semiconductor devices and optical coatings are the main applications benefiting from thin films construction.

Chapter seven provides industrial applications of thin films in chips, solar cells, biotechnology, photonic crystals, stainless steel, etc. The concept of photonic crystal structure to optimise the thickness and refractive index of the materials required to make anti-reflection coatings has been included. Chapter eight is exclusively devoted to consumer applications including microactuators, artificial jewellery, liquid crystal displays, cellular phones, artificial retina, and so on. Chapter nine is dedicated to military applications covering military optics and coating. The concluding chapter gives summary of the book.

Dr KN Chopra
Shri AK Maini

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We are thankful to the referees for their valuable suggestions and technical vetting of the monograph.

We are grateful to the Director, DESIDOC and his team members including Ms. Vinod Kumari, Ms. Alka Bansal, and Ms. Kavita Narwal for the support and follow up in publishing the monograph.

Dr KN Chopra

Shri AK Maini

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Chapter 1

Thin Films: Technology and Applications

1.1 INTRODUCTION

The main purpose of depositing thin film optical coatings on an optical surface is to so modify it to provide environmental protection and/or improve optical performance. Thin films are thin material layers ranging in thickness from fractions of a nanometer to several micrometers. Electronic semiconductor devices and optical coatings are the main applications benefitting from thin films construction.

Some work is being done with ferromagnetic thin films as well for use as computer memory. Ceramic thin films are also in wide use. The relatively high hardness and inertness of ceramic materials make this type of thin films coatings of interest for protection of substrate materials against corrosion, oxidation, and wear. In particular, the use of such coatings on cutting tools may extend their life by several orders of magnitude.

1.2 TYPES OF THIN FILMS

1.2.1 Classification of Thin Films Coatings

Thin films are classified in many ways, mainly, according to the materials used for the coatings, the damage threshold, the strength, and the characteristics, etc. There are metallic coatings, and dielectric coatings. The metallic coatings always have lot of absorption and have only limited applications. The dielectric coatings have practically negligible level of absorption, and hence, are very useful for various applications in optics, e.g., laser systems and imaging instruments. Higher laser damage threshold coatings are useful for high power lasers. The coatings with higher mechanical strength and higher abrasion resistance are used for mechanical tools for increasing their life.

1.3 THIN FILMS DESIGN

1.3.1 Designing of Dielectric Coatings

The designing of dielectric mirrors is a very interesting and specialised topic, and some important work is done by Willy[1], Dobrowolski[2,3], *et al.* and Tikhonravov[4]. A dielectric coating consists of two or more thin layers of different transparent optical

materials. The design is done by considering the Fresnel reflection coefficient from a single interface between two materials and is carried out by keeping in mind the function to be performed by the coated component, e.g., high reflection, anti-reflection (AR), polarisation, chromatic dispersion, beam splitting or filtering, etc. Other parameters to be considered are the operational wavelength range and the desired angle of incidence.

It is interesting to note that even if the value of the reflection coefficient is small for a particular interface because of small difference of refractive indices of the materials of the layers surrounding it, it is still possible to obtain a very high overall reflectivity of the component because of the contributions of the reflection from other interfaces, based on constructive interference in a certain wavelength range.

The well known laser mirrors have all the optical layer thicknesses equal to a quarter of thickness of the desired wavelength. The design becomes more complicated if the desired effect is to be obtained in a broader region of wavelengths. For AR coatings, design is based on the destructive interference. It is also possible to design coatings for other specific functions like beam splitting, polarisation, a combination of beam splitting and polarisation, edge filters (like short wave pass filters, long wave pass filters, and band pass filters), a combination of desired reflection properties in different wavelength ranges (like AR at certain wavelengths and high reflection at other wavelengths or vice versa), and chromatic dispersion, i.e., dichroic mirrors.

The design of dielectric coatings is a complete topic in itself, and has to be learnt by the optical design engineer. Here the subject is being introduced and its physics is discussed. It is to be understood that the complexity of the design depends upon the nature and the number of functions to be performed by the coated component. The more complicated the functions, and more the number of functions, the more complex is the design. In some cases, the number of layers is small (3 to ~21), and in some cases, it can be very high indeed (in the vicinity of 100). The design also depends on the difference of the values of refractive indices of the materials of the layers. Resonator mirrors in lasers are mostly dielectric-coated mirrors, as these are free from absorption associated with the metallic coatings, and leading to very high reflection (99.99 per cent or higher). However, these do not give shining lustre like appearance as is the case for metallic mirrors. Instead, they appear transparent, since they have high reflection at a particular wavelength, and also because the materials have negligible absorption.

The reflection properties of a multilayer (ML) mirror can be calculated by matrix method, in which each layer is associated with 2×2 matrix, and the matrix of the design is obtained by multiplying together the matrices of all the layers. The resultant matrix can be used to calculate the complex amplitudes of the reflected and the transmitted waves, along with the field distribution in the multilayer structure. The frequency dependence of these coefficients results in achieving chromatic dispersion, i.e., designing of dichroic mirrors. It is to be noted that nowadays, many numerical optimisation software based on the matrix method are commercially available. Some refined softwares like Monte Carlo method are also available for efficient optimisation of the designs.

(a) Anti-reflection Coatings

The AR coatings (optical thin film coatings for reducing reflections from surfaces) are one of the most important coated components. These AR coatings are dielectric thin film coatings applied to an optical surface to reduce the optical reflectivity of that

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ABOUT THE AUTHORS

Dr Kamal Nain Chopra retired as Scientist G from Laser Science and Technology Centre (LASTEC), Defence Research and Development Organisation (DRDO). Dr Chopra received MSc (Physics), MTech. (Optoelectronics), and PhD (Physics), all from Indian Institute of Technology, Delhi. He has worked in School of Thin Films Coatings, University of St. Jerome, France, and Thin Films Coatings Division, University of Innsbruck, Austria. Besides, he has got training in Thin Films Industries–M/s Balzers, Liechtenstein (Switzerland) and M/s Elettrorava, Torino, Italy.

His major achievements are in the areas of design and growth of thin films for a range of laser and optoelectronic devices and systems developed at LASTEC over the last 25 years. These coatings have found applications in a range of state of the art systems like Ring Laser Gyro, Drishti Eye care laser, Alexandrite laser, Nd:YAG laser-based systems and so on. His other important contributions are establishment of thin films coating facilities, which includes Balzers Vacuum Coating Unit with electron beam deposition facilities, Elettrorava Dual Ion Beam Sputtering Unit, and Hind High Vacuum Coating Unit. He was also instrumental in establishing characterisation facilities including Nomarski Differential Interference Contrast Microscope, Talystep Surface Profiler, and Gaertner Ellipsometer and so on. He has authored about 110 publications in journals, symposia and conferences of National and International repute

Shri Anil Kumar Maini, Director, LASTEC, DRDO, received BE (Electronics) from Punjab Engineering College, Punjab University, Chandigarh in 1977. He joined DRDO in 1978 and has accumulated more than 32 years of R&D experience in all aspects of product design and development related to military optoelectronics and EOCM systems. His areas of expertise include optoelectronic simulator and sensor systems, laser systems, power electronics, digital electronics and related technologies. He has spearheaded the development of low power non-lethal directed energy laser systems for LIC applications.

He has been at the hub of the development of complex test systems for seeker heads of electro-optically guided precision guided munitions (PGM) which have been successfully field tested by user services. He also carried out pioneering work in the indigenous development of dual role EOCM laser systems for anti-sensor and anti-personnel applications, family of laser warning sensors for defensive electro-optic counter measures (EOCM) and Programmable laser target designators for field evaluation of laser guided bomb delivery systems.

He has authored ten books and about 150 technical articles and papers in National, International journals, magazines and conferences. He has two patents to his credit.

ABOUT THE BOOK

This monograph is intended to provide an overview of the design and development of thin films and their deposition techniques for various applications. Thin films possess a wide range of applications in both civil as well as military sectors. This includes their use for protection of materials from corrosion, oxidation, and wear, increasing transmission or reflection in a certain wavelength region, and also in filters, colour separation, fire-resistance, high temperature superconductors, silicon devices, anti-fog, and memory devices.

This book is aimed at creating awareness about the applications in military and civil sectors, which are classified as scientific, industrial, and consumer. This book should be useful for engineers, researchers and young scientists, presenting them the state-of-the-art about thin films and their deposition techniques. This book also provides an overview of the R&D effort of LASTEC in the area of thin films.

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