Available online at www.sciencedirect.com
ScienceDirect
ELSEVIER
Progress in Surface Science 81 (2006) 387–401
Progress in SURFACE SCIENCE
www.elsevier.com/locate/progsurf

Review

Vacuum coating of plastic optics

Ulrike Schulz *, Norbert Kaiser

Fraunhofer Institute for Applied Optics and Precision Engineering IOF, Albert-Einstein-Str. 7, 07745 Jena, Germany

Commissioning editor: A.W. Kleyn

Abstract

Vacuum technologies for the deposition of optical interference coatings on polymer substrates, based on long-term experience in glass coating, have been under development for about 20 years. A growing market for precision optical elements and consumer optics moulded from thermoplastic polymers requires antireflective properties and hard coatings. Owing to the manifold chemical and physical properties of optical polymers, special efforts are essential for each type of plastic to find polymer-capable coating conditions. The main focus of this article is on evaluating the state of the art in vacuum-coating processes applied to plastics today, and on discussing specific coating techniques and evaluation procedures. A better understanding of the complex interactions between low-pressure plasmas and the various polymer materials will be a key factor in making durable plastic optics for future applications; achieving this will be a challenge to surface scientists.

Keywords: Plastic optics; Coating on plastics; Vacuum coating; Antireflection; Plasma surface modification

Contents

1. Introduction 388
2. Coatings for plastic optics 389
3. Trends in vacuum-coating techniques 392
4. Wet-chemical coatings 393
5. Moth-eye structures to achieve antireflection properties. 394
6. Problems with vacuum coating 395

* Corresponding author. Tel.: +49 3641807344.
E-mail addresses: ulrike.schulz@iof.fraunhofer.de, schulz@iof.fraunhofer.de (U. Schulz).

0079-6816/$ - see front matter
doi:10.1016/j.progsurf.2006.07.001

6.1. Interactions between plasmas and polymers . . . 395
6.2. Diversity of materials . . . 396
6.3. Stress in coatings on plastics . . . 396
6.4. Difficulties with testing procedures . . . 397
7. Challenges to surface scientists . . . 398
8. Summary . . . 398
Acknowledgements . . . 399
References . . . 399

1. Introduction

Rigid plastic optical components will replace parts made from glass whenever improved properties or lower costs can be achieved with plastic elements. The classical fields of application are eyeglasses and complex-shaped lenses for precision optical systems. In the near future, transparent plastics with optical-grade surfaces will be used on a large scale for covering car instruments and as refractive and diffractive elements for optical sensors. In the case of precision optical parts, transparent polymers such as poly-methyl methacrylate (PMMA) and bisphenol-A polycarbonate (PC) have been common for more than 50 years. Moreover, many new materials optimized for optics – among them polyamides, polyether sulfones, cycloolefin polymers and its copolymers – have been developed during the last few years [1]. These thermoplastic polymers can be processed cost-effectively into high-precision forms by injection moulding or hot embossing. A selection of transparent thermoplastics and their properties is shown in Table 1.

Coatings can enlarge the area of application of polymer optics. Antireflection (AR) properties are required for many precision optical elements and for consumer optical products such as eyeglasses and covers for displays. Another motivation for coating plastics results from the mechanical and chemical properties of organic polymers. Protective coatings increase the resistance of the polymer to abrasion, protect the polymer from chemical attack, or reduce gas flow through or from the polymer. In addition, coatings can be helpful for modifying the surface energy, thereby adjusting the wettability by water or oil [2,3].

When used as substrates for vacuum coating, organic polymers are much more complicated than inorganic glasses. Their various chemical structures can lead to various reactions in contact with chemicals or a plasma. Modern vacuum-coating processes are generally associated with short-wavelength radiation sources. The most significant threats to the long-term stability of coated plastics are caused by vacuum ultraviolet (VUV) during the deposition process and by environmental factors, including humidity and the ultraviolet radiation in daylight. Both types of threat can result in immediate or slow changes in the bulk or interface properties after coating. Because of the complex differences between polymer materials, every plastic material requires specific conditions for coating.

The focus of this article is on evaluating the state of the art in vacuum-coating processes applied to plastics today. In practice, many coating procedures for polymers were initially adapted from glass-coating processes by empirical variation of parameters. On the other hand, surface scientists have studied the interactions between polymer surfaces and highly energetic radiation for many years [4–6]. For the generation of a stable interface between a