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Editorial

Special Issue "Advanced Coating Technology by Physical Vapor Deposition and Applications"

Chuen-Lin Tien

Department of Electrical Engineering, Feng Chia University, Taichung 40724, Taiwan; cltien@fcu.edu.tw

Coating technology covers a wide range of fields. At present, in areas ranging from semiconductors, optoelectronics, microelectronics, machinery, aerospace, medical biotechnology, to even livelihood industries, we can see the added value of coating technology, whether in making impossible products possible or creating higher economic value. With the sustained efforts of the global industry, academia, and research circles, we will continue to improve, providing better coating quality, more reliable manufacturing methods, and more energy-saving and better optimized control methods. We look forward to sharing the research and development results of the academic community.

This Special Issue introduces the advanced coating technology, based on high vacuum environments, which can deposit thin films with specific functions onto the surface of substrates. There are many different methods for depositing thin films. The thin-film deposition process is generally divided into physical vapor deposition (PVD) and chemical vapor deposition (CVD). The former requires high vacuum or ultrahigh vacuum conditions. The PVD process uses a vacuum chamber to vaporize a solid and deposit it onto a target substrate, atom by atom, via methods such as sputtering and evaporation. The result is an extremely thin, extremely pure coating, made using a technology that is more environmentally friendly than many other coating technologies. It is generally necessary for thin-film systems to have good optical properties, a relatively low cost and a simple production process [1]. On the other hand, chemical vapor deposition (CVD) is a chemical process used to produce high-purity, high-performance thin solid films [2]. The CVD process mixes source materials with one or more volatile precursors that serve as carrier devices [3]. The advantages of the CVD process include the uniform coating of irregular surfaces and the ability to produce thin films of extremely high purity and density. Unfortunately, the CVD thin films need to be made at a higher temperature, and the process leads to higher residual stress of the coating and substrate, which requires the moderate adjustment of deposition parameters to control the residual stress. Unlike the CVD process, PVD is a process in which materials are evaporated at a high temperature in a vacuum. When the vapor is condensed to the surface, it will provide thin solid layers of pure coating with which to deliver a harder surface to the component. The coating process is environmentally friendly, meets FDA requirements, and is non-toxic.

PVD is characterized by the process of the material moving from the condensed phase to the gas phase and then back to the film condensed phase. The basic principle of the PVD process can be divided into three steps: (1) The vaporization of coating materials, including the evaporation, separation or sputtering of coating materials. (2) The migration of atoms, molecules or ions in the coating, such as occurs in various reactions after particle collisions. (3) The high-temperature vapor deposition of atoms or molecules onto the surface of low temperature substrate. In addition, PVD can improve the performance of products by improving the surface quality of various thin films, helping to create a smoother surface that reduces roughness [4].

Evaporation and sputtering are two commonly used PVD techniques. The evaporation process is a coating technology that uses resistance or electron beam heating to reach the melting temperature of the material to be evaporated under high vacuum conditions

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so that atoms evaporate, reach and adhere to the surface of the substrate. During the evaporation process, the substrate temperature has a great influence on the properties of the evaporated thin film. Usually, the substrate also needs to be properly heated, so that the evaporated atoms have enough energy to move freely on the surface of the substrate in order for a uniform film to be formed. When the substrate is heated above 150 °C, a good adhesion can be formed between the deposited film and the substrate without peeling off. The traditional sputtering process uses plasma to bombard the target with ions and thus to knock out the atoms on the target surface. These target atoms are emitted as gas molecules and reach the substrate, where they are deposited. After the adhesion, adsorption, surface migration, nucleation and other processes are complete, a thin film is grown on the substrate. Therefore, the sputtering process can achieve excellent deposition.

The purpose of this Special Issue is to provide an academic exchange platform, allowing researchers to share the latest research results and promote further research on advanced coating technology on the basis of physical vapor deposition and its related applications. The topics covers novel PVD coating techniques, optical interference coatings, simulation and modeling in PVD processes, multilayer thin-film applications, mechanical residual stress in thin films and coatings, etc.

Optical coating techniques have been widely used in scientific and industrial applications. The major processes for physical vapor depositions include thermal evaporation and sputter deposition. The sputtering technique can densify the deposited thin film and reduce the residual stress in film/substrate system when the deposition temperature below 150 °C [5–7]. A large area sputtering target helps to achieve uniform coating for thin-film deposition, so that the thickness can be controlled by easily adjusting the deposition time. Unfortunately, the process can cause film contamination due to the diffusion of impurities evaporated from the sources during evaporation process. Therefore, there are still some limitations in the selection of coating materials due to their melting temperature.

Compared with other coating technologies, magnetron sputtering technology has incomparable excellent performance, such as fast deposition speed, low temperature, environmental protection and other excellent performance, so this technology has been widely used [8]. A new high power pulsed magnetron sputtering (HiPIMS) coating technology has been widely noticed and attracted. The HiPIMS power supply is able to prevent the abnormal glow discharge that conventional magnetron sputtering can operate normally from turning into arc discharge. The plasma density of HiPIMS is about three orders of magnitude higher than that of conventional magnetron sputtering and its strong adjustable ionization rate is close to 70%–100%. High peak target power densities facilitate the generation of high-density plasmas with efficient ionization mechanisms for sputtered target materials. Studies have demonstrated that the high ionization of the plasma leads to increased ion bombardment of the grown film, which is beneficial to the thin-film coatings with dense microstructure and excellent adhesion to substrates [9–11]. Thus, HiPIMS can easily deposit various thin films of very good quality on substrates even at greater distances than conventional magnetron sputtering.

Thin films have different applications in various fields; furthermore, they play a significant role in the study and development of devices with unique and special properties. In addition, optical multilayer coatings have a wide range of properties and can be used in various component applications. Optical coatings that combine high and low refractive index thin films have many applications. Examples include distributed Bragg reflectors [12], notch filters [13–17], antireflective coatings [18–22], narrow-bandpass filters [23–27] and flexible displays [28,29], etc. These application components have received a great deal of attention. For instance, the high-refractive-index and low-refractive-index layers of the distributed Bragg reflectors are prepared by the oblique-angle deposition technique [12]. The reflectivity of a single-material DBR with three periods reaches 72.7%, which is in good agreement with the theory.

Generally, multilayer thin film interference filters have different optical transmission properties in the ultraviolet/visible/near-infrared spectral range. The band stop filters can be used to block the transmission over a given spectral range. The basic structure of the thin film interference filters is the quarter-wave stack. Several approaches have been used in the past for producing notch filters [13–16]. For example, rugate and discreet layer designs are two main approaches. Notch filters have a narrow rejection band within a much wider high transmission band. Such filters are not easily designed due to the width of the rejection region is defined by the index ratio of the materials that make up the coating. A multilayer thin film notch filter is designed for improving the visual quality. The notch filter with a center wavelength of 480 nm is based on a 9-layer non-quarter-wave stack design, and the transmittance at the center wavelength is about 15%. The multilayer notch filter, produced by the electron beam evaporation method combined with ion-assisted deposition technology, has low residual stress and low surface roughness [17].

As we all know, anti-reflective coatings (ARCs) are indispensable components in many optical systems [18]. When the demand for highly curved optical elements increases, complex technical modifications are required to achieve better uniformity on the curved substrate if the PVD method is used for coating [19]. Tikhonravov et al. [20] proposed the design of anti-reflection coatings used for the wavelength of 8–10 μm in infrared spectral band making use of the design approach that allows layer thicknesses to be limited within specified ranges. The influence of antireflective thin film on improving the function of silicon solar cells was investigated theoretically by single-layer and double-layer anti-reflection coatings [21]. In 2022, Feng et al. [22] reported reports that SiO_2 was being used to fabricate broadband antireflection (AR) films onto fused silica substrates. By precisely controlling the graded refractive index of the SiO_2 layer using glancing angle deposition, the residual reflectance of the graded broadband AR coating can reach an average value of 0.59% in the spectral range of 400–1800 nm.

The band-pass optical filter is one of the optical interference filters that is the most widely used in imagining and machine vision systems [23]. Narrow band filters have squarer tops to their transmission band, thus allowing more energy in the pass band through the filter. Design methods allow the shape to be squarer still if three materials are used in constructing the filter. A narrow bandpass filter has a square top over its pass band, thus allowing more energy to pass through the filter. The design method allows for a squarer shape if three materials are used in the construction of the filter [24,25]. Generally, the design of multilayer narrow-bandpass filter is very sensitive to the variation of film thickness, and the change of film thickness is too large, which will have the effect of reducing the overall optical performance. Recently, thin-film optical sensors have attracted increasing attention in the development of technologies such as biometrics. Multilayer dielectric thin films have been used to modulate the optical properties of specific wavelength bands to achieve spectral selectivity of thin-film narrow bandpass filters [26]. Besides, a modified Fabry–Perot filter design was reported to implement a wide-angle bandpass optical filter with higher transmission, angular insensitivity, and sideband elimination. To fabricate an angle-insensitive filter, silver and silicon thin films are used in the optical coating process [27].

Although the glass or metal can be used to encapsulate organic light-emitting diode (OLED) devices in rigid displays, flexible display applications require thin-film-based permeable barriers. When applied to the emissive surface of a display, these thin films need to be mechanically flexible and transparent in the visible region [28]. Therefore, state-of-the-art technologies for thin-film permeation barriers and multilayer structures for OLEDs, as well as the potential optical effects of transparent multilayer thin films on displays [29], are also worthy of investigation.

Thin films and multilayer coatings composed of different kinds of materials are commonly used in various functional devices. Due to the manufacturing process, the thermo-mechanical integrity of these devices is becoming a major issue and is closely related to residual stresses. In this Special Issue, the concept of residual stress in coating systems will be investigated and discussed. Based on the force and moment balance of the film/substrate system, analytical models are developed to predict the residual stress in multilayer thin film structures or PVD coating systems and then effectively control the residual stress of multilayer films in order to improve the reliability of thin-film devices [30,31]. It can provide important data for the optimal design and production of optical thin-film devices. In the case of coating-based systems or multilayer film structures, the subject matter used in the above definitions becomes a composite system of film and substrate.

For visual optics applications, blue-light filtering lenses (BFL) are used to protect the eyes from blue light that can be harmful to the visual system. Since BFL attenuates transmitted light, it also reduces object contrast, which may also affect visual behavior such as the perception of object speed which reduces with contrast. BFL reduces exposure to harmful blue light, but it has unintended consequences for important visual behavior, such as motion perception. BFL is commercially produced and sold without either manufacturers or consumers being aware of its effect on visual function. Indeed, the literature [32,33] shown that BFLs can reduce object luminance and colour contrast sensitivity and affect photostress recovery times, particularly mesopic vision at low contrast levels. It should be noted that the relevant research still needs further investigation in to verify its validity. We aim to publish relevant academic research results in this Special Issue.

Conflicts of Interest: The authors declare no conflict of interest.

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