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Optical Coatings: Applications and Metrology †

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Abstract: The development of optical coatings experienced rapid growth in the last few decades for a wide range of applications. The strong demand is motivated by the progress of new generation sources, large-scale facilities, new lithography arrangements, innovative methods for materials science investigation, biosensors, and instruments for space and solar physics observations. The research activities carried out at the Padova branch of the Institute for Photonics and Nanotechnologies of the National Research Council range from the design and characterization of optical components for space activities, to the development of nanostructured coatings for tools such as biosensors and surface plasmon resonance devices. We present a selection of the expertise, methods and ongoing activities.

Keywords: optical coatings; metrology; thin films; SPR

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1. Introduction

The Institute for Photonics and Nanotechnologies (IFN) of Italy's National Research Council (CNR) carries out pioneering research in several fields of photonics. The Padova branch stands out in the technological activities related to the development of optical devices. The application fields range from space instrumentation to sensors platforms, include the optical metrology and are strongly oriented to applied physics and technology transfer.

Thin films and optical coatings are a transversal topic, common to all activities just mentioned. Over the years, the CNR-IFN focused on the design of nanostructured thin films to be used as sensitive layers of biosensors [1,2], mirrors [3], filters, phase retarders [4,5] and polarizers. We have developed many of these devices for space mission instruments [6,7], but their use in laboratory was fundamental for research in basic and applied physics [4,5]. For example, the development of ellipsometric and polarimetric systems is one of the topics of great interest for the study of solar physics and celestial bodies, and at the same time, suitable for applications at laboratory scale. We have recently developed an ellipsometric system dedicated to the study of the optical properties, the composition and the contamination of materials [4,5]. One of the applications was the study of the optical behavior of 2D materials in the vacuum ultraviolet (VUV) spectral range [7].

In the field of biosensors, nanostructured films find a very interesting application in the use of innovative metals layers for surface plasmon resonance (SPR) platforms based on prism and fiber [1,2]. The goal is to improve the sensitivity, detection accuracy, dynamic range and application fields of this type of bio-device.

This manuscript is a short review of selected activities carried out at the CNR-IFN in Padova.

2. Optical Characterization

The reflectometers available in the laboratory (CNR-IFN, Padova) cover a wide spectral range extending from the extreme ultraviolet (EUV) to the visible wavelengths. The equipment was designed for testing the optical response of samples at variable incidence angles, in θ-2θ configuration. Figure 1 exhibits the system recently assembled for the optical characterization in the visible range. It consists of a compact stabilized broadband light source (360–2600 nm), a rotator stage to hold the sample at a desired working angle, and a spectrometer coupled with a cosine corrector for the detection.

Figure 1. The design and the photograph exhibit the reflectometer at CNR-IFN in Padova optimized for the optical characterization in the visible range.

The measurements, in reflection and transmission modes, can be performed for any type of sample with no restrictions in size. The optical response can be tested with polarized and un-polarized light in order to investigate the polarization properties of the specimen of interest.

Figure 2 refers to the measurement of a silicon sample with a thin layer of silicon oxide on the top. This material was selected as a substrate for the development of VUV phase retarders and the performance has presumably been compromised by aging effects. The blue line depicts the experimental measurement, the orange one describes the theoretical curve.

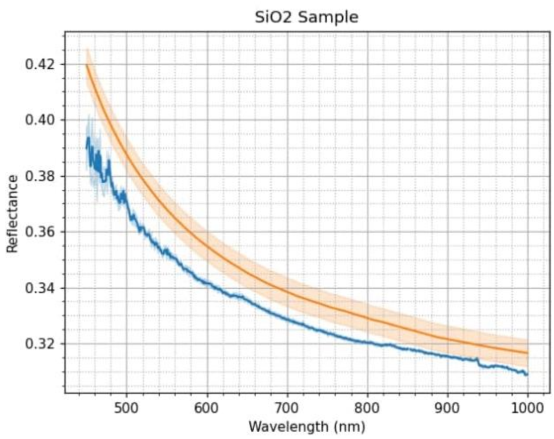

Figure 2. The plot depicts the experimental (**blue**) and theoretical (**orange**) trend of a silicon substrate with a thin layer of silicon oxide on the top.

Optical characterizations at shorter wavelengths (30–400 nm) are possible by using a normal incidence Johnson-Onaka reflectometer. Figure 3 exhibits the design of the equipment.

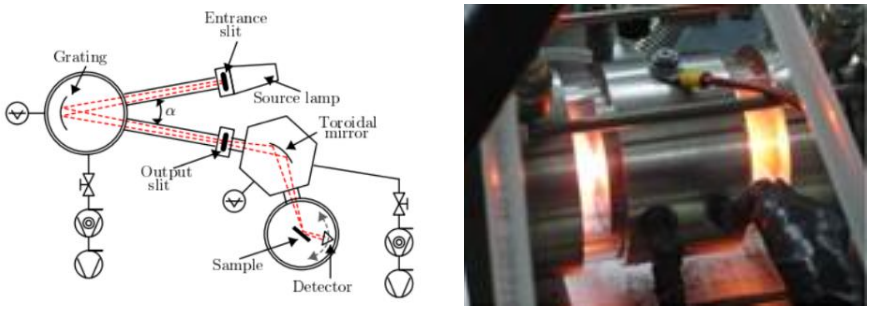

Figure 3. The EUV-VUV-UV Johnson-Onaka reflectometer (**left**); the picture (**right**) exhibits the hollow-cathode lamp that can be coupled with the Johnson-Onaka reflectometer.

The dispersion element mounted on the reflectometer is a Pt-coated toroidal grating with 600 lines/mm. The main radius is 0.5 m and the subtended angle between the entrance and the exit slits is 25°. A toroidal mirror working at 45° incidence angle focuses the monochromatic radiation on the sample. In the experimental chamber, the samples are hosted on a holder that can be rotated to the desired the incidence angle.

We have recently implemented this facility with a rotating linear polarizer optimized for the VUV. In this way, the reflectometer is suitable for ellipsometric measurements [4,5]. The upgraded system has recently been used for the characterization of phase retarders for EUV-VUV wavelengths [4,5]. In this spectral range, study and design of phase retarders and polarizers is a delicate issue because the optics are mainly reflective and require the optimization of nanostructured multilayers. Coatings based on aluminium thin film deposited onto silicon substrates have good performances, but are also affected by deterioration, aging and contamination. The ellipsometric equipment allows to determine the optical response and the presence of oxidation layers and contaminants with sub-nanometer accuracy [4,5].

By combining ellipsometric and synchrotron measurements, we have investigated the optical properties of graphene onto silicon oxide at hydrogen Lyman–alpha spectral line (121.6 nm) [7]. We have determined the optical constants of monolayer and trilayer graphene and experimentally observed its optical anisotropy. Furthermore, the presence of graphene induces a shift of the pseudo-Brewster angle of the silicon oxide [7].

For the future, we are planning a systematic study of several 2D materials such as MoS_2, whose properties are interesting for many technological applications.

3. Optical Coatings for SPR Devices

The development of optical coatings for SPR devices is an interesting topic in several respects. The research of innovative materials that offer better performance than gold and silver, and the technological optimization of the deposition onto several substrates such as fiber and plastic slabs are two of the topics we are working on [1,2]. We have collaborated on the fabrication of a palladium/gold bilayer designed for an SPR sensor based on D-shaped optical fiber (POF). The novel SPR-POF platform was optimized to work in the 1.38–1.42 refractive index range, where it exhibits excellent performances in terms of sensitivity and signal to noise ratio [2].

Another interesting application we dealt was the development of innovative biochips for Kretschmann SPR tools [1]. The new chips are based on palladium thin films deposited on plastic substrate. The plastic support is low cost and commercially appealing, the palladium is interesting from the scientific point of view, showing inverted surface plasmon resonance (ISPR) response. The biochips were tested for the detection of DNA chains, selected as the target of the experiment, since it can be applied to several medical early diagnostic tools, such as different biomarkers of cancers or cystic fibrosis [1].

Author Contributions:

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