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Dimensional characterization of biperiodic imprinted structures using optical scatterometry

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ABSTRACT

In this paper, we report on the characterization of biperiodic imprinted structures using a non-destructive optical technique commonly called scatterometry. The nanostructures consist of periodic arrays of square and circular dots which were imprinted in a thermoplastic polymer by thermal nanoimprint lithography. Optical measurements were performed using spectroscopic ellipsometry in the spectral region of 1.5–4 eV. The geometrical profiles of the imprinted structures were reconstructed using the Rigorous Coupled-Wave Analysis (RCWA) to model the diffraction phenomena by periodic gratings. The technique was also adapted for large scale evaluation of the imprint process. Uniqueness of the solution was examined by analyzing the diffraction of the structure at different experimental conditions, for instance at various angles of incidence.

1. Introduction

In recent years, nanoimprint lithography (NIL) has attracted much attention due to its high resolution patterning capabilities with a high throughput and relatively low cost [1–3]. NIL has emerged as one of the enabling techniques for submicron patterning of materials in a wide range of applications such as solar cells texturization for light management [4–6], surface enhanced Raman spectroscopy [7], optical metamaterials [8], IC fabrication processes [9], to name a few.

In a typical NIL process, nanopatterns are replicated onto a deformable imprint material by mechanically pressing a nanostructured mold into the substrate. Thus, the resolution of NIL is not limited by the wavelength of the light as it is the case for most other lithographies. Two known variants of NIL are thermal nanoimprint (or hot embossing) and UV-assisted nanoimprint lithography. Both setups require pressing the mold and the sample together under certain conditions. In the first one, the polymer is first heated above its glass transition temperature before being pressed, and thus becomes liquid. The mold is then separated from the sample after cooling down the system. In the second setup, a photo (UV) curable liquid resist is used and the mold is made of transparent material. When pressing the mold and the sample together, UV light is applied through the mold to initiate the polymerization, thus leading to the solidification of the resist. In both cases, a thin residual layer is intentionally left in order to avoid any mechanical contact between the mold and the substrate. The patterns are transferred to the underneath substrate using standard etching process, after removing the residual thickness. In this case, the residual layer thickness is a key parameter and should be controlled over the entire imprinted area because it contains information about the overall process. Microscopic imaging, such as scanning electron microscopy, is commonly used to fulfill this need. This technique is destructive because the sample has to be cleaved for cross-sectional imaging. Alternative solutions based on optical metrology are being considered to complement standard metrology such as SEM and AFM.

Scatterometry is an optical technique that analyzes the light scattered from a periodic structure to reconstruct the correspondent geometrical profile. This latter has been successfully employed for 1D gratings and imprinted structures [10–14], and rarely for 2D patterns [15,16]. To the best of our knowledge, optical scatterometry has not been applied yet for biperiodic imprinted structures characterization.

In the present work, we report on the characterization of biperiodic structures using optical scatterometry. Specular spectroscopic ellipsometry is employed for the measurement of the scattered optical signature. The structures were fabricated by hot embossing nanoimprint lithography. The patterns, imprinted in a thermoplastic polymer, consist of square and rounded pillars of a period of 1.5 and 0.5 μm, respectively. We also show the capability of this technique for accurate determination of the residual layer thickness. Scatterometry is also adapted for large-scale evaluation of imprinting process. The uniqueness of the geometrical parameters is investigated by analyzing the diffraction signature of the patterned structure at different angles of incidence.

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2. Experimental

2.1. Samples fabrication

The key step in nanoimprint lithography is the fabrication of the mold having the desired patterns. Two molds fabricated in silicon substrates were used in our work. The first one is made of a square array with 1.5 μm square dots; the second one is made of a square array of 0.4 μm-period circular dots. They were fabricated using DUV lithography for photoresist patterning and standard plasma etching process for Si etching. Molds have been treated chemically (hydrophobic) to prevent any adhesion between the mold and the imprint polymer during NIL process. Thin films of NEB22 resist, based on poly (hydroxyl-styrene) polymer and designed by Sumitomo chemical, were first coated on the substrates. The glass transition temperature of the resist is 80 °C. The NIL experiments were carried out in EVG520HE tool. At 130 °C substrate temperature, the mold is pressed into the resist during 5 min with 40 kN mechanical pressure. Then, the mold and the substrate are separated at room temperature. A schematic illustration of the process is shown in Fig. 1.

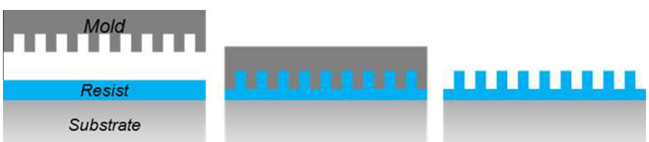

Fig. 1. Nanoimprint lithography basic process. The mold is pressed into the resist under temperature greater than the glass transition temperature of the resist. The mold and the substrate are separated at room temperature.

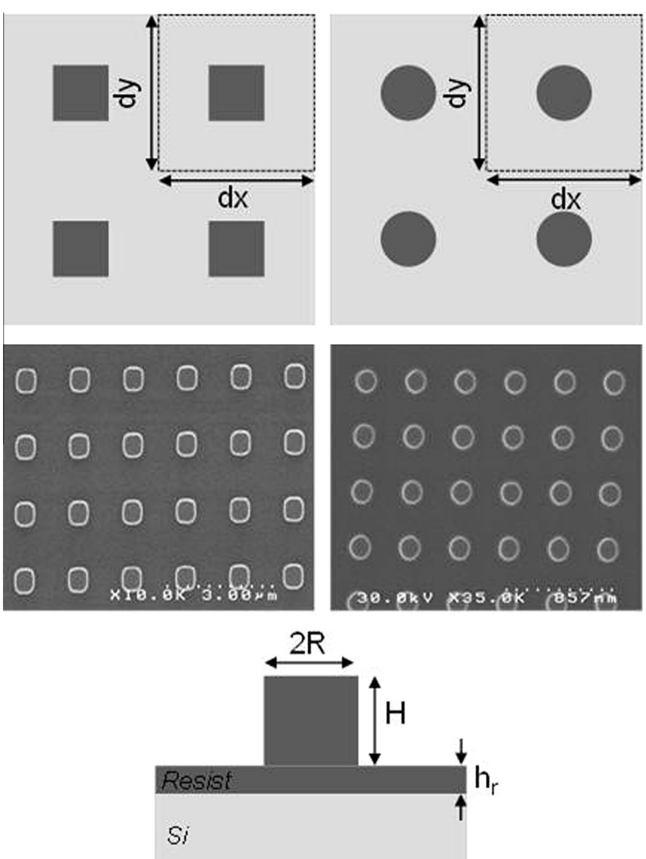

Fig. 2. Geometrical profiles of two different structures: square (upper left) and circular dots (upper right) based models. $2R$ is the square side or the dot diameter, H is the height of the grating and h_r is the residual layer thickness. dx and dy are the periods in both direction x and y.

2.2. Optical measurement and data analysis

The optical scattered signatures of the patterns were measured using a phase-modulated variable angle spectroscopic ellipsometer (UVISEL Horiba-Jobin Yvon). Spectroscopic measurement has the advantage of having additional information contained in the spectrum. Intensities (I_s,I_c) in the 0th order diffraction are collected for all samples. They are expressed as follows:

$$I_s = sin\psi \cdot sin\Delta; \quad I_c = sin2\psi \cdot cos\Delta$$

ψ and Δ are given by the so called fundamental equation of ellipsometry:

$$\rho = r_p/r_s = tan\,\psi\, e^{i\Delta}$$

where r_p and r_s are the complex reflection coefficients for p- and s- polarized light, respectively. More details on this technique can be found elsewhere [17].

The reconstruction of the geometrical profile from the measured signature is mathematical and can be viewed as an optimization problem. This step, generally called the inverse problem, can be solved using different approaches [11,13,18–21]. The geometrical parameters are fitted using the Levenberg–Marquardt regression algorithm. A multilayer modal approach by Fourier expansion [22] is used to analyze the electromagnetic wave diffraction by periodic structures.

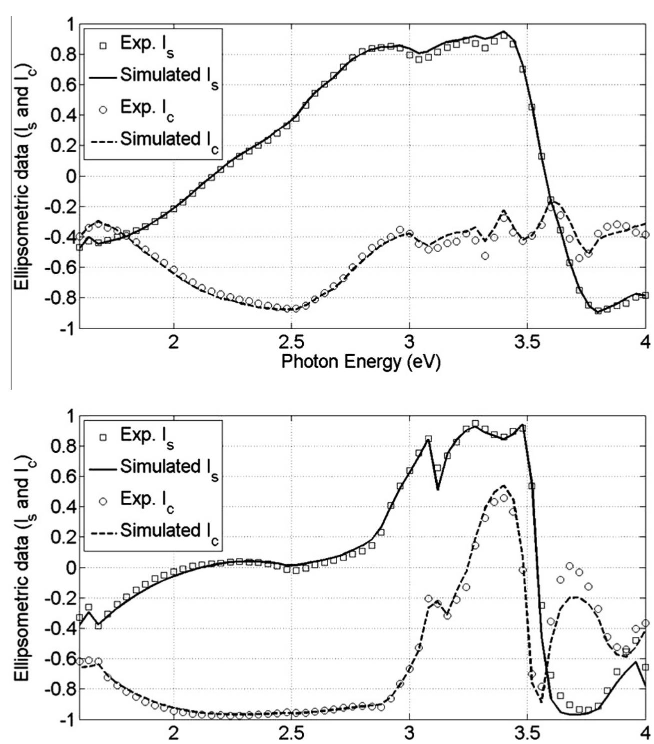

Fig. 3. Fit of experimental ellipsometric data (I_s and I_c) of 1.5 μm-period square dots grating (top) and 0.4 μm-period circular dots grating (bottom). Incidence angle is 60° in both cases.