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Antireflection sub-wavelength gratings fabricated by spin-coating replication

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Abstract

We fabricated an antireflection subwavelength grating (SWG) on a polymethyl methacrylate (PMMA) by a spin-coating replication technique. Silicon molds of a two-dimensional tapered grating of 200 nm period and 90 nm deep have been obtained using electron beam lithography and reactive ion etching. Replication has been done by direct spin-coating a 9.35 μm thick PMMA on the mold, followed by an appropriate mounting on a glass substrate. The transmittance in the wavelength region ranging from 500 to 800 nm was measured and compared with the calculation results on the basis of rigorous coupled-wave analysis. At these wavelengths, the transmittance of the SWG was increased in comparison with that of the flat PMMA sheet, in good agreement with the theoretical calculations.
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1. Introduction

Surface-relief gratings with periods smaller than the wavelength of light, named sub-wavelength gratings (SWGs), behave as antireflection surfaces [1–20]. The SWGs, particularly one with a tapered line of hole gratings, suppress reflection over wide spectral bandwidth and large field of view. The SWGs are more stable than multi-layered thin films used conventionally as antireflection surfaces, since they are fabricated from single materials. In addition, the transmitted wave fronts are not degraded. Because of these advantages, SWGs are useful for large number of applications such as light emitting diodes [17], photo detectors [18], photovoltaic cells [19] and glass components [13,20]. The challenge is how to produce them at a high throughput and low cost. One of the proposed techniques is the well known nanoimprint

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lithography (NIL) method in which a rigid mold is pressed into a heated poly-methyl methacrylate (PMMA) layer spin-coated on a substrate [21–26]. Previously, Chou et al. [21] have shown the fabrication of a metal dot array with a period of 120 nm and diameter of 25 nm uniformly. A high aspect ratio line structure with a height of 200 nm and width of 70 nm has also been obtained [23]. It was believed that the nanoimprint technique is well suited for the pattern transfer of SWGs because they can be easily produced over a large area at low cost. Han et al. [4] fabricated two-dimensional SWGs with 300 nm period gratings on polycarbonate and on photoresist. Gombert et al. [10] fabricated a two-dimensional SWG with a 300 nm period grating on organically modified ceramic (ORMOCER) film. David et al. [15] fabricated one and two-dimensional SWGs with 200 nm period gratings on polycarbonate. All these experimental demonstrations were based on *hot embossing* which uses a rigid mold and a heating and cooling process for high pressure imprinting. Because of the thermal dilatation, the scale of the embossed surface gratings can be different from that of the mold. Moreover, the embossing time is in general longer than that required by other methods without thermal process.

In this paper, we propose a replication method of antireflection SWGs by direct spin-coating a thin polymer layer on the mold. High-resolution electron beam (EB) lithography and reactive ion etching were used for the fabrication of the mold of 200 nm period surface gratings on a silicon substrate. PMMA has been chosen as working material because of its high resolution, low cost and optical transparency in the wavelengths between visible and near-infrared regions. By spin-coating, the PMMA layer thickness can be controlled precisely by adjusting the viscosity of the coating material and the rotational speed. Moreover, since the thin PMMA films are flexible, antireflection structures can be mounted on curved optical structures for some interesting applications. PMMA is inferior to SiO_2 in thermal and optical qualities, and also degraded with UV exposure. However, it is used for various applications, which are optical waveguides and plastic lenses, such as pick-up lenses, Fresnel lenses and eyeglasses. The SWGs which consist of PMMA can be applied to these applications without spoiling their thermal and durable characteristics. To optimize the grating design, theoretical calculations have been done based on the *rigorous coupled-wave analysis* (RCWA) proposed by Moharam [27,28]. Then, the reflectivity measurement was performed for wavelengths ranging from 500 to 800 nm in visible region.

2. Fabrication method

Fig. 1 shows the fabrication process flow used in this work. First, patterns are defined by a JEOL 5D2U vector scan generator at 50 keV energy with an electron beam (e-beam) resist, which is a single layer PMMA resist of 950K molecular weight and 150 nm thickness spin-coated on a silicon substrate (a and b). Afterward, the patterns are transferred into the silicon substrate (c) by reactive ion etching (RIE) with SF_6/CHF_3 gas mixture (1:2), followed by removal of the remaining PMMA resist using trichloroethylene. In order to facilitate the peel off of the replica from the mold, the silicon mold is placed in a box of vaporized chlorotrimethylsilane 99% (TMCS) for 10 min. Then, PMMA of 950 kmol and solids contents 15% in Anisole is spin-coated on the mold at 1500 rpm to obtain a thickness of 9.35 μm (d). Next, the sample is kept at the room temperature for 30 min for degassing,

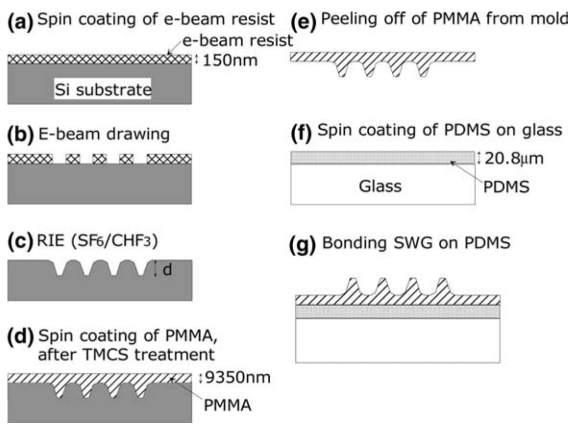

Fig. 1. Steps used in the fabrication process of the replica of SWG.

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