Influence of Imprint Conditions on the Quality of Submicron Scale Imprinted Patterns

D. Jucius1*, V. Grigaliūnas1, A. Guobienė1,2

1Institute of Physical Electronics, Kaunas University of Technology, Savanorių 271, LT-3009 Kaunas, Lithuania
2Department of Physics, Kaunas University of Technology, Studentų 50, LT-3031 Kaunas, Lithuania

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Significance of imprint lithography as a high-throughput, low-cost means for the micro- and nanometer scale patterning of various substrates is expected to grow in the near future. Thus, investigations of the influence of imprint conditions on the quality of imprinted patterns are of great importance. If imprints are in the form of diffraction gratings, measurement of intensity of reflected light in selected diffraction orders may be used as an effective means for the fast and nondestructive evaluation of imprints. This method was used for the testing of submicron scale patterns imprinted into the Shipley Microposit S1805 photoresist with the thickness of nearly 0.2 µm. Tests have showed that optimal conditions of imprint are achieved when temperature is set to 120 – 130 °C, holding time is 60 – 90 seconds, and pressure is equal to 4 MPa. In the region of 100-110 °C imprint quality is very poor because of the dominating elastic response of polymer layer. Raising of the temperature up to 140 °C leads to the noticeable liquefaction of the polymer. Thus, rapid separation of the mold and substrate may cause certain damage of the imprinted grating.

Keywords: imprint lithography, diffraction gratings, scatterometry.

INTRODUCTION

Lithography plays significant role in the micro-technologies. In addition to the classical method of optical lithography, which reached the optical diffraction limit, nowadays for the patterning of substrates interference lithography, direct electron beam lithography, X-ray lithography, scanning probe lithography and other advanced methods are used [1]. They are potentially capable to ensure a high fidelity of the produced patterns. However, these methods are pretty complex and time consumable.

Imprint lithography as a high-throughput, low-cost, nonconventional lithographic method with the resolution down to 10 nm was proposed and investigated recently [2, 3]. During the process of imprint surface relief of a patterned master - the "stamp" - is transferred into the thin polymer film coated onto a hard substrate using heat and pressure. The initial thickness of the polymer film must be tuned to the pattern sizes, their fill factor, and the depth of the pattern relief in the master [4]. The embossing is carried out at temperatures well above the glass transition temperature of the polymer, where it has a relatively low viscosity and can flow under the force. As soon as the stamp is in full area contact with the polymer, which is the case when the polymer fills the whole stamp relief pattern conformally, the effective pressure decreases and imprint slows down significantly due to the polymer transport phenomena [5, 6]. Thus, a residual layer of polymer remains within the compressed regions and protects the rigid stamp from contact with the hard substrate. This residual layer has to be removed by anisotropic reactive ion etching in order to result in a polymer mask on top of the substrate. For easy separation of stamp and sample after imprinting, the polymer should feature good adhesion to the substrate and substantially lower adherence to the stamp. Imprint lithography is shown to be suitable for the production of various microstructures [7 – 9].

Our group has successfully employed imprint lithography to form photonic structures in silicon substrate [10 – 13]. The aim of this work is investigation of the influence of imprint parameters such as temperature, time and pressure on the quality of submicron scale imprinted patterns.

EXPERIMENTAL TECHNIQUE

Nickel mold in the form of diffraction grating with a feature density equal to 1300 grooves per mm was used as an imprint stamp with desired submicron scale features. 3D image of the mold surface evaluated by atomic force microscope (AFM) Nanotop NT-206 is presented in Fig. 1.

![AFM image of the nickel mold for the imprint experiments](image)

Substrates for the imprint were prepared by a spin coating of a thin layer of commercially available Shipley Microposit S1805 photoresist onto the prescribed standard...
n-Si<100> wafers. Curing of the photoresist at a 110 °C temperature for 15 min took place before use. Thickness of the photoresist layer was measured by a laser ellipsometer Gaertner L-115. It was revealed to be (210 ±10) nm. Part of the substrates had additional vacuum evaporated Al interlayer of 100 nm thickness between Si and photoresist. This interlayer is often important for the subsequent technological steps [10].

Imprint tests were performed using a simple home-built mechanical press. The stamp and the substrate were placed on parallel stages. Stamp was heated up to the imprint temperature and brought into a physical contact with the substrate. After the predetermined temperature and pressure holding time was over separation of the stamp and substrate took place without any additional cooling. Imprint temperature was varied from 100 °C up to 140 °C. Printing was performed at a pressure from 2 to 6 MPa. Holding time was varied from 15 to 90 seconds. Surface area of the imprint was nearly 1 cm².

Quality of the imprints into polymer layer was estimated quantitatively using a nondestructive method of optical scatterometry. It is well known that optical beam reflected from the illuminated periodic pattern is decomposed into several diffraction orders. Any change in the profile of grating is accompanied by the redistribution of the light intensities between various orders. Moreover, efficiency of diffraction for a given profile decreases if deviation of surface features from the ideal grating is more pronounced [14 – 16]. Thus, measurement of intensity of reflected light in selected diffraction orders was chosen as an effective means for the fast evaluation of imprint quality in our experiment. Intensities of reflected monochromatic light were measured using a special stand for the investigations of He-Ne laser light (λ = 632.8 nm) diffraction. Eight measurements were carried out and averaged for each imprint.

RESULTS AND DISCUSSIONS

Tests of the imprint stamp in the laser stand allowed us to observe its scattering peculiarities as well as to determine quantitatively distribution of reflected light intensity in various spectral orders (Fig. 2).

![Fig. 2](image)

**Fig. 2.** Distribution of reflected light intensities after illumination of Ni imprint stamp by the He-Ne laser

It can be seen that most of the reflected light is concentrated in –1, 0, and +1 spectral orders. Contribution of higher orders is negligible and tends to decrease as dealing

![Fig. 3](image)

**Fig. 3.** Mean intensities of diffracted laser light in first order of diffraction as a function of printing temperature and holding time for the substrates with Al interlayer. Imprint pressure is (a) 2 MPa, (b) 4 MPa, (c) 6 MPa with polymer coated surfaces. This may cause some problems in measurement of intensities. Zero spectral order corresponds to the simple mirror - like reflection
from the illuminated surface. Thus, for the evaluation of imprint quality, only –1 and +1 diffraction orders were chosen. Arithmetical means of intensities of the reflected light in –1 and +1 spectral orders were calculated for each set of imprint conditions and used for subsequent analysis of results. Moreover, random nature of the imprint process was reduced by averaging intensities of diffracted light of five imprints made at the same imprint conditions.

Mean intensities of diffracted laser light in ±1 diffraction orders as a function of printing temperature and holding time at the three different imprint pressures are presented in Fig. 3. Results were collected for the substrates with Al interlayer. However, it was revealed that elimination of the interlayer was responsible only for the substrates with Al interlayer. However, it was revealed that elimination of the interlayer was responsible only for the change in reflection coefficient of the substrate and had no any more significant influence on the distribution of reflected light.

It is evident from Fig. 3 that in the region of 100 – 110 °C imprint quality is very poor and almost independent of the imprint pressure and holding time. This is related to the dominating elastic response of polymer layer at low temperatures. Some improvement can be achieved only at high pressures. However, using of the pressures larger than 6 MPa greatly enlarge risk of a mechanical damage of the substrates. Thus, more desirable way is to enlarge imprint temperature.

Best quality of imprinted gratings was achieved when temperature was set to 120 – 130 °C and holding time was large enough (60 – 90 seconds) to settle a thermal equilibrium between the stamp and the substrate. It can be seen that 4 MPa is a sufficient pressure to produce the imprints of a good quality under the before mentioned conditions and its subsequent enlargement up to 6 MPa do not give any significant improvement.

Further raising of the temperature leads to the noticeable liquefaction of the polymer. Thus, rapid separation of the mold and imprinted substrate, as a rule, causes some degree of degradation of the imprinted grating.

CONCLUSIONS

Tests of the submicron scale patterns imprinted into the Shipley Microposit S1805 photoresist with the thickness of nearly 0.2 µm have showed that optimal conditions of imprint are achieved when temperature is set to 120 – 130 °C, holding time is 60 – 90 seconds, and pressure is equal to 4 MPa.

In the region of 100 – 110 °C imprint quality is very poor because of the dominating elastic response of polymer layer. Raising of the temperature up to 140 °C leads to the noticeable liquefaction of the polymer. Thus, rapid separation of the mold and substrate may cause certain damage of the imprinted grating.

REFERENCES