UV nanoimprinting lithography using nanostructured quartz molds with antisticking functionalization

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Abstract

In this paper, we report the results obtained by the application of the SET FC150 equipment for UV Nanoimprinting Lithography (UV-NIL), using nanostructured quartz molds, which were properly functionalized by an antisticking treatment. The used process condition, established after an accurate optimisation of the imprint parameters (time profiles of force, substrate temperature and UV irradiation), are described in details. In order to accurately characterize the pattern transfer on a negative resist deposited on a Si substrate, optical microscopy (OM) and atomic force microscopy (AFM) were carried out both on the quartz mold and on the structures obtained on resist after UV NIL process. In particular, we show that the used process conditions allowed us to obtain a resist residual thickness <10 nm on the Si substrate at the bottom of the imprinted region, which is optimal to perform subsequent plasma treatments without degrading the features on resist. Finally, some examples of structures obtained on resist with deep submicron dimensions are reported.

Introduction

Nanoimpriting lithography (NIL) is a nonconventional lithographic technique for high-throughput patterning of polymer nanostructures at great precision and low cost [1, 2]. Unlike traditional lithographic approaches, which achieve pattern definition through the use of photons or electrons to modify the chemical and physical properties of the resist, NIL relies on direct mechanical deformation of the resist material and can therefore achieve resolutions beyond the limitations set by light diffraction or beam scattering that are encountered in conventional techniques.

Two main implementations of NIL have been demonstrated to date, i.e. hot embossing lithography and UV-nanoimprinting lithography (UV-NIL).

In the first approach, a thermoplastic resist material is used, whose viscosity is greatly reduced upon heating at temperatures higher than a critical value (the glass transition temperature Tg); therefore, the hard mold is able to penetrate in this fluid material; finally, its layout remains imprinted in the resist after its cooling down below Tg. For this application molds have to be fabricated with materials with high thermal conductivity.

In the NIL the curing of the resist materials during mold imprinting is obtained by UV light illumination. Dedicated UV curable resists have to be used for UV-NIL; however, higher resolution pattern transfer on resist can be achieved by this approach than with hot-embossing.

Fig.1 *FC150 equipment by SET installed in the class 10 clean room at CNR-IMM, Catania*

Experimental details

In our experiments we used the FC150 system by SET, which is equipped both with the harm for "hot-embossing lithography" and with the arm for UV-NIL. The results reported in the following concern the applications for UV-NIL.

Fig.2 *Details of the FC150*

In Fig.1 and Fig.2, the FC150 system installed in the class 10 clean room at CNR-IMM in Catania is illustrated.

The resist used in these experiments was a negative UV- curable resist, the mri6020 by Microresit. The used molds, made by quartz to be transparent to UV light, were purchased by NTT, Japan. Their dimensions are 1 cm × 1 cm and their layout consists of features represented by sets of lines with different widths and separations and dots of different diameters and separations.

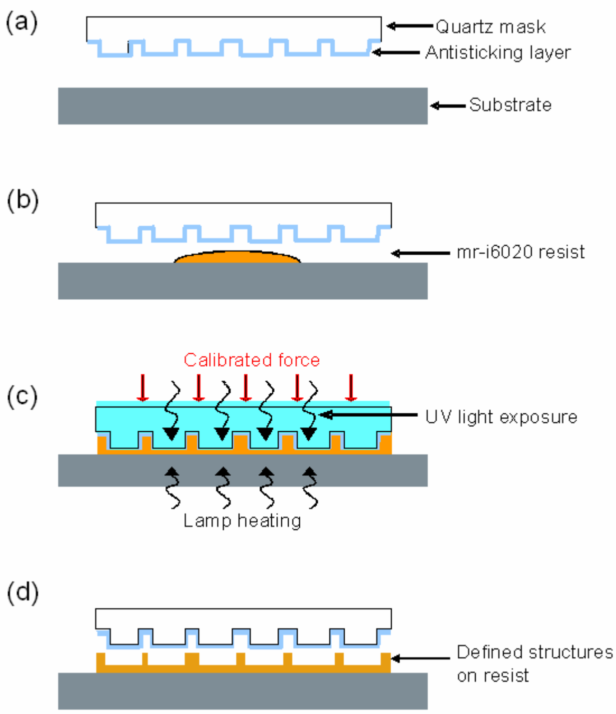

Fig.3 *Schematic description of the UV-NIL procedure to imprint on UV curable resist the nanostructured layout present on the quartz mold.201*

In order to upload the mold by the vacuum line in the thermo-compression arm, its backside was glued at the centre of special quartz supports purchased by SET, using a dedicated epoxy. These quartz supports are designed to fit with the vacuum lines in the thermo-compression arm.

In the following, the optimised UV-NIL process conditions will be described in details. Therefore, the obtained results will be discussed.

The procedure adopted to transfer on resist the pattern of the quartz mold is schematically illustrated in Fig.3 and it consists of the following steps:

(a) A preliminary alignment of the mold surface with respect to the substrate surface (a Si wafer) is carried out, in order to achieve an accurate parallelism between the two surfaces.

(b) A drop of the mr-i6020 resist with well calibrated dimensions is deposited on the substrate. The FC150 system is equipped with a dispenser, allowing to precisely controlling the drop dimensions.

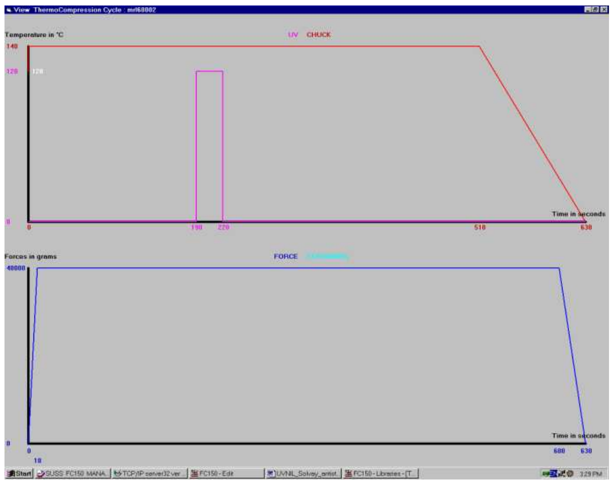

Fig.4 *Profiles of the applied force, of the substrate temperature e of the UV –light intensity as a function of the time during the optimised UV NIL process*

(c) The mold is approached to the sample surface and, after contact; a fixed force (40 kg in the present experiment) is applied. The substrate is heated at a temperature of 140 °C, making it fluid. Under these conditions, the nanometer structures in the hard quartz mold will penetrate in the fluid resist. Finally, the resist curing is achieved by UV radiation emitted from an UV source (□=365 nm) in the thermocompression arm though transparent quartz mold. The time profiles of the applied force, of the substrate temperature and of the UV radiation intensity are reported in Fig.4.

(d) Finally, the mold is lifted from the substrate surface, thus leaving the nanometer features on the cured resist. In this step the antisticking functionalization of the mold surface plays a crucial role. In fact not only it must prevent the mold from sticking to the sample, but it should ensure a long lifetime of the mold, avoiding that resist residuals fill its nanostructured features and degrading the quality of next imprints.

Results and discussion

In Fig.5 some optical microscopy images of the structures obtained on the resist are reported at different magnifications. The used quartz mask layout contains features represented by lines and dots of different dimensions (till a minimum dimension of 100 nm) and with nominal depth of 190 nm, according to the manufacturer's specifics. As it is evident in Fig.5, these features are present on resist, after the Nanoimprinting process. All the features in the 1×1 cm mold layout were transferred on resist.

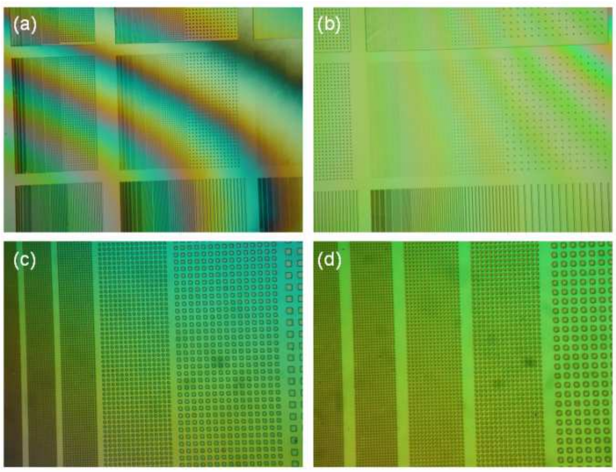

Fig.5 *Optical microscopy images at different magnifications on the pattern imprinted on the mri6020 resist.*

In order to characterize in details the result of the nanoimprinting procedure, AFM measurements were carried out both on the mold and on the resist surfaces after imprinting.

In Fig.6 an AFM image obtained on a feature in the quartz mask is reported. A depth of ~187 nm is obtained, consistent with the manufacturer's specifics. However, it is also evident the presence of thin resist particles on the surface.

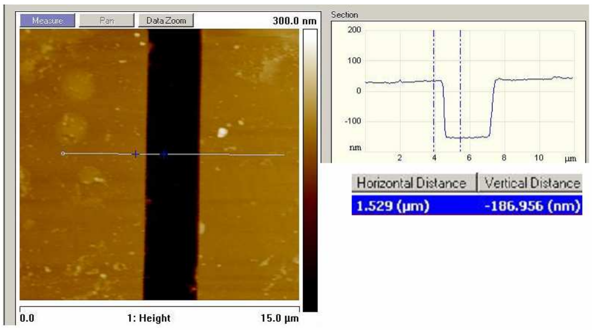

Fig.6 *Atomic force microscopy (AFM) image on a feature of the quartz mold treated with the antisticking functionalization (the measure was carried out after several imprintings). A step height of ~187 nm is measured, in good agreement with the manufacturer's specifics.*

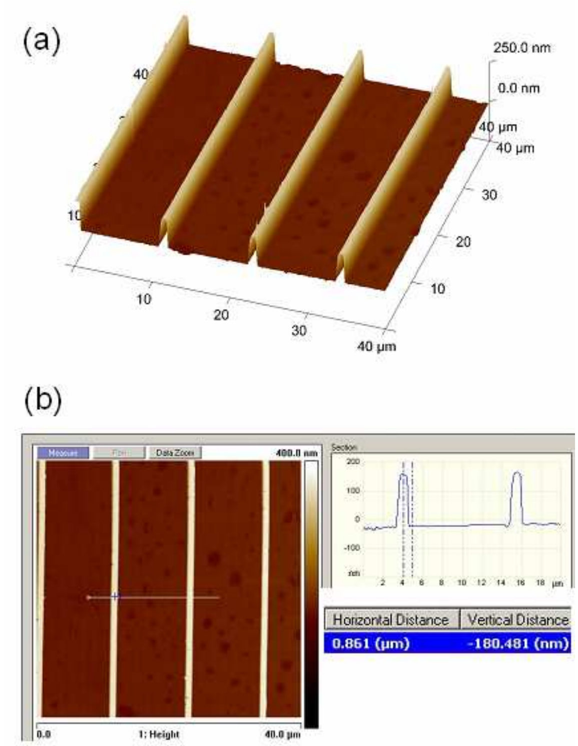

Fig.7 *AFM image on the imprinted pattern on resist. The measured height of the features is ~180 nm, indicating the presence of a residual resist layer thickness <10nm on the Si substrate*

In Fig.7 an AFM analysis on the imprinted pattern on resist is reported. The height of the features if ≈180 nm; hence, the residual layer thickness <10 nm remains on the Si substrate at the bottom of the imprinted region. The presence of this residual resist after the imprinting is highly desirable because it guarantees that the hard quartz mold did not cause damage on the Si substrate. Usually, this residual layer is removed by a soft plasma etching. Under this point of view, this thickness is optimal, because it can be easily removed without regrading the features on resist.

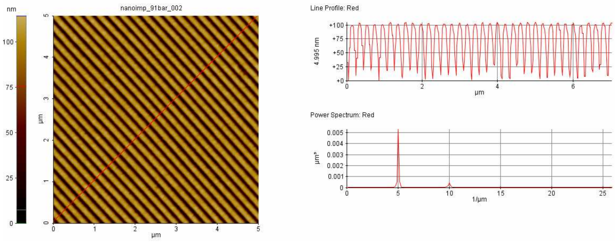

Fig.8 *AFM image on submicron features with line shapes obtained on resist. The pitch between adjacent features is 200 nm.*

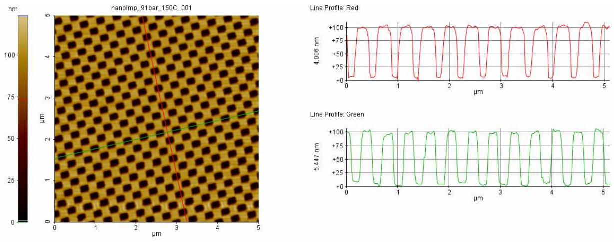

Fig.9 *AFM image on submicron features with dot shapes obtained on resist.*

Finally, in Fig.8 and Fig.9, AFM images of submicron features with line and dot shapes obtained on resist are reported, respectively.

In Fig.8, we show a scan line on the morphology in direction perpendicular to the stripes. The power spectral density (PSD) on that line profile is calculated, showing that the pattern is highly ordered (only one peak in the PSD spectrum); the pitch between adjacent features is 1/5 □m, i.e. 200 nm. Since the strip lines and separation are equal, the single feature dimension is 100 nm.

Conclusion

In conclusion, we reported the results obtained by the application of the SET FC150 equipment for UV Nanoimprinting Lithography (UV-NIL), using nanostructured quartz molds, which were properly functionalized by an antisticking treatment. By optical microscopy we verified that all the features (lines and dots of different dimensions and spacing) present in the 1 cm $\times$ 1 cm layout of the mold were transferred on the UV curable mr-i6020 negative resist. AFM analyses both on the quartz mold and on the structures obtained on resist indicated that, in the used process conditions, a resist residual thickness <10 nm is present on the Si substrate at the bottom of the imprinted region. This thickness is optimal to perform subsequent plasma treatments without degrading the features on resist. Finally, some examples of structures obtained on resist with deep submicron dimensions were reported.

References

[1] L. J. Guo, Adv. Mat., 19, 495 (2007).

[2] S. Y. Chou, P. R. Krauss, P J. Renstrom, Appl. Phys. Lett. 67, 3114 (1995).