High quality patterns produced by nanoimprint lithography and inductive coupled plasma etching

B. Bilenberg [a], C. C. Welch [b]

[a] NIL Technology, Oersteds Plads, DTU Building 347, Kongens Lyngby, DK-2800 Denmark
telephone: +45 – 3171 9037 e-mail: bb@nilt.com
[b] Oxford Instruments Plasma Technology, North End, Yatton, Bristol, BS49 4AP, UK
telephone: +44 1934 837000 e-mail: colin.welch@oxinst.co.uk

Key words: Nanoimprint lithography, ICP etching, pattern transfer

For nanoimprint lithography (NIL) etching processes are crucial as well as the imprinting process. In order to transfer high quality patterns into the substrate by NIL three etching processes must be optimized: the etching process used to produce the NIL stamp (typically in combination with electron beam lithography, EBL), the etching process used to remove the residual layer after imprinting, and the etching process used to transfer the pattern into the substrate. In this paper we demonstrate how inductive coupled plasma (ICP) etching gives excellent results in all three of these steps.

Introduction

Nanoimprint lithography (NIL) is a versatile, cost effective, flexible and high throughput method for fabrication of below 10 nm structures [1] with a wide range of application within e.g. storage [2], optics [3] and bio-sensors [4]. The basic NIL sequence is illustrated in Fig. 1.

Etching by the low pressure of inductively coupled plasma (ICP) is a familiar means of patterning now being increasingly used for high quality patterning at the nano-scale. The high ion density, low pressure ICP etch regime provides excellent control over etched profiles and critical dimension (CD) [5] and is thus suitable for the three critical etching steps in the NIL process sequence as demonstrated below.

Stamp production

UV NIL stamps have been produced from 500 µm thick fused silica wafers which were prepared with 40 nm sputtered chromium, Cr, and 120 nm ZEP520A [6] by spin coating. The stamp pattern with down to 30 nm structures was defined by 100 kV EBL (Jeol JBX9300FS), dose 220 $\mu C/cm^2$, and developed for 2 min in ZEP-N50 [6]. An octofluorocyclobutane (C_4F_8)-oxygen (O_2) mixture was used for ICP etching of the fused silica. Fig. 2 shows an optimized stamp etch. 30nm features have been etched to 200 nm depth at a uniform rate of 85 nm/min with a selectivity over the Cr mask better than 200:1. The profile is vertical and trench free. Fig. 3 shows control of profile and trenching.

Descum

After imprinting there is inevitably some residual polymer under the stamp protrusions, typically 10-20 nm thick for stamp protrusion heights of 100-200 nm. Before pattern transfer into the substrate this residual polymer must be removed with uniform and minimized CD and profile change. ICP processing succeeds here by enabling stable low pressure and anisotropic conditions. Cooling of the substrate also improves the anisotropy. Fig. 4 shows a good descum of a polystyrene residual.

Pattern transfer into substrate

The requirements to the final substrate etch depend on the application and so are much more diverse than the stamp etch and descum. Examples are given of two ICP silicon etch processes with complementary attributes for nanoscale etching [7]. The first is a room temperature process using a C_4F_8-SF_6 gas mixture, Fig. 5. The second is the cryogenic process using a SF_6-O_2 gas mixture, Fig. 6. Control of etched silicon profile by means of the ICP process parameters is shown in the figures.

Conclusion

The use of ICP for the three etching steps in a typical NIL process scheme has been demonstrated. ICP etching shows superior capabilities regarding etching of high performance NIL stamps with well controlled profiles. The stable low pressure descum process possible with ICP effectively removes the residual polymer after imprinting with minimal change of CD and ICP is also perfect for transferring the imprinted pattern into fused silica or silicon.

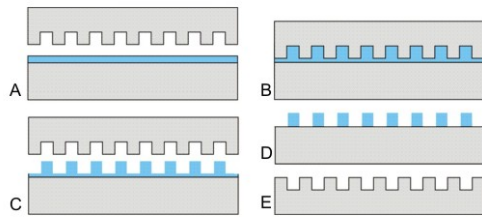


Fig. 1. Schematic of the NIL process.
A. A stamp is fabricated in typically silicon or fused silica by electron beam lithography (EBL) and dry etching. B. The stamp is pressed into a soft thermoplastic, thermosetting or UV-curable polymer on a substrate combined with heating or UV radiation C. Polymer cured and stamp released from substrate D. Residual imprint polymer under stamp protrusions removed by 'descum' process E. Imprinted pattern transferred into substrate by dry etching.

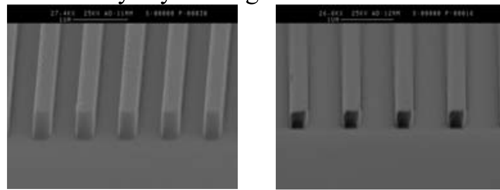


Fig. 4. Descum of polystyrene pattern on quartz. CD constant at 350 nm before (left) and after (right) descum. The parameters were O_2 flow rate 10 sccm, Pressure 1 mTorr, ICP 600 W, RIE bias 10 W, He backside 10 Torr, Electrode temperature 10°C.

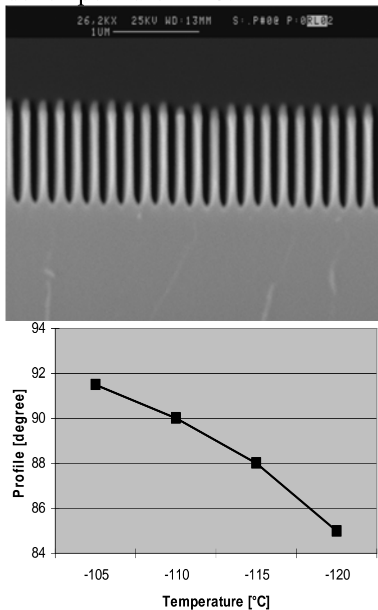


Fig. 6. 1μm deep Si lines with 10:1 aspect ratio etched by ICP cryo process
Profile control by temperature (bottom)

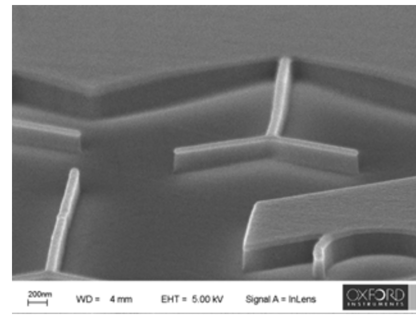


Fig. 2. SEM image of optimized fused silica stamp etch (30nm features to 200nm depth). The chromium hard mask is still present on top of the structures.

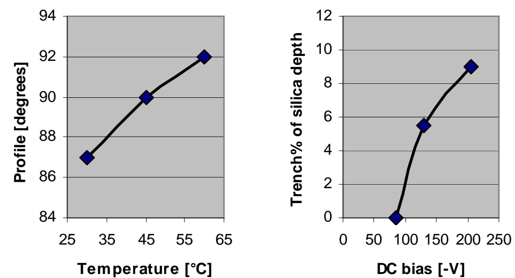
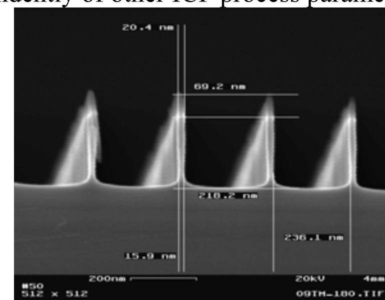


Fig. 3. Control of profile (left) and trenching (right) for fused silica stamp ICP etch. The profile is controlled by the temperature and the trenching is controlled by the DC bias (which is varied by means of the RIE bias power largely independently of other ICP process parameters.



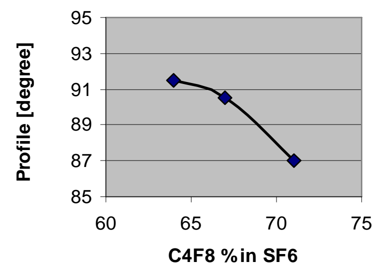


Fig.5. 16 nm Si lines etched by C_4F_8-SF_6 ICP process. Profile control by C_4F_8% (bottom)

References

[1] S. Y. Chou *et al.* J. Vac. Sci. & Technol. **B 15** (1997) 2897.
[2] T. Glinsner *et al.* Solid State Technology **48** (2005) 51.
[3] M. B. Christensen *et al.* Optics Express **15** (2007) 3931.
[4] B. Bilenberg *et al.* Microelectronic Eng. **83** (2006) 1609.
[5] A.L.Goodyear, D.L. Oylnick *et al.* J.Vac.Sci.Technol. **B 18 6** (2000). 3471.
[6] Zeon corporation Tokyo Japan *www.zeon.co.jp*
[7] C.C.Welch *et al.* Microelectronic Engineering **83 4-9** April-September 2006 1170.