Dimension reduction of nano-gratings by controlled melting of patterned polymer mask

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Nanostructures are fundamental to many applications in nano-electronic as well as nano-fluidic and bio-NEMs devices. Nanostructures are typically defined by lithography, e.g. e-beam lithography, and followed by etching or liftoff to transfer patterns from resist to substrate. As dimensions are controlled by dose in particle beam lithography, it is challenging to produce high resolution nanoscale patterns over large areas consistently. Several unconventional methods, e.g. edge lithography [1] and Si oxidation reduction [2], have been reported to reduce dimensions in the pattern transfer step so that the requirements in high resolution lithography are relaxed. Both are limited by high process temperature (>900 ℃), surface and edge variation, or are only applicable to Si.

In this study, we develop a simple and well controlled process of dimension reduction to single-digit nanometer regime by controlled melting of lithographically (nanoimprint lithography) defined polymer lines to reduce the slope of the grating sidewall, followed by oblique angle metal evaporation and inductively coupled plasma (ICP) etching (Fig. 1). This low-temperature method offers good dimensional control and is applicable to a wide variety of materials. One application to make nanoimprint molds with narrow trenches (~10 nm) is demonstrated. First, 50K PMMA is imprinted with a mold containing a large area of 100 nm line and space gratings (Nanonex). Then, the sample is heated above the glass transition temperature of PMMA, causing partial melting of the imprinted PMMA gratings while still preserving the overall imprinted profile. Extent of melting, characterized by the change in sidewall slope of imprinted lines, can be well controlled by duration (Fig. 2) and temperature of heating. Then, a metal layer is deposited onto the sloped PMMA gratings by oblique angle evaporation. By adjusting the angle during metal evaporation, it is possible to control the size of the opening in the metal coating on the imprint profile (Fig. 3). The metal serves as a mask for etching of exposed PMMA, between openings in the metal, by oxygen ICP as well as transfer of patterns to the oxide layer by ICP etching in a mixture of C_4F_8, CHF_3 and Ar. Using this process, the trench width can be precisely controlled down to as small as 10 nm or less (reduced from original 100 nm line and space PMMA gratings) and resulting patterns exhibit excellent quality and controllability (Fig. 4).

This method provides a low cost and low temperature process to shrink pattern dimensions over large areas with high fidelity. The drawback of the technique is inability to reduce the pattern pitch. This method has been applied in our group to make low cost narrow grating molds and Si nanowires without using expensive high resolution lithography.

[1] Y.P. Zhao et al., *J. Micromech. Microeng.* 18(6), 2008.
[2] Q.F. Xia et al., *Nano Lett.* 8 (11), 2008.

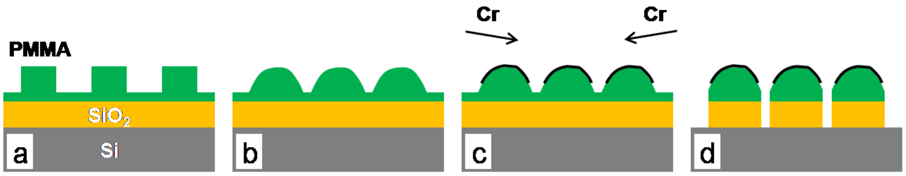

Fig 1: Schematic of dimension reduction process: a) imprinted grating before and b) after melting; c) oblique angle metal evaporation; and d) etch to substrate.

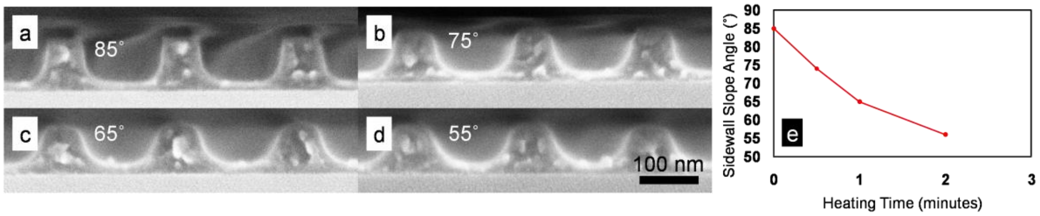

Fig 2: SEM X-section showing grating profiles with measured sidewall slope angle: a) before and b) after heat treatment at 125˚C for 30 seconds; c) 1 minute, d) 2 minutes; e) Sidewall slope angle as a function of heating time.

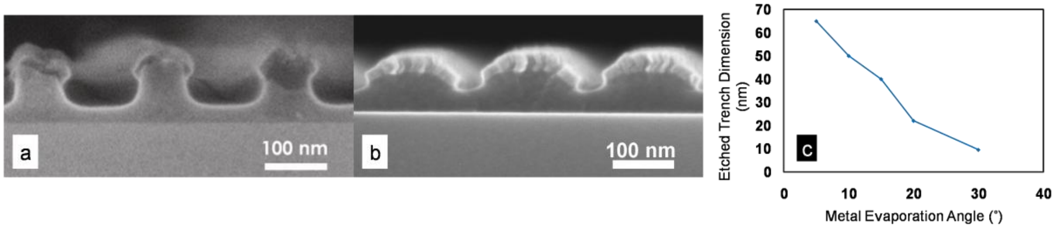

Fig 3: SEM X-section showing gratings after oblique angle Cr evaporation on gratings (a) without heat treatment and (b) with heat treatment;
(c) Etched trench dimension in oxide as a function of metal evaporation angle.

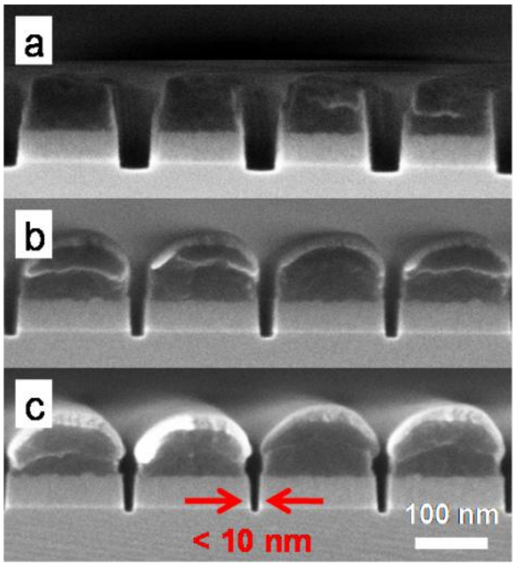

Fig 4: SEM X-section showing patterns etched into oxide after oblique angle Cr evaporation on melted imprint profile at (a)10˚, (b) 20˚ and (c) 30˚.