Fabrication of high aspect ratio nano-trenches and characterization of spin-on dielectric filling

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Spin-on dielectric (SOD) materials are becoming increasingly popular in replacing chemical vapor deposition (CVD) and high density plasma (HDP) deposited materials for shallow trench isolation (STI), pre-metal dielectric (PMD) and inter-layer dielectric (ILD) in semiconductors. Due to aggressive shrinking of semiconductor design rules, one of the most challenging requirements for candidate SOD is void-free gap filling in trenches of ever-increasing aspect ratios and decreasing widths. Fabrication of such nano-trenches over the large areas to test filling of SOD materials is challenging. Here, we demonstrate the fabrication of high aspect ratio nano-trenches (AR of >30, trench width <25 nm) to simulate STI structures for 22 nm semiconductor node using inexpensive nanoimprint lithography and inductively coupled plasma (ICP) etching. These trenches were then used to evaluate high-aspect ratio gap filling property of proprietary new polysilazane (PSZ) based SOD (Dongjin Semichem) by transmission electron microscopy (TEM).

First, the photoresist (50K PMMA) patterns were formed by nanoimprint lithography, followed by a size reduction process using controlled polymer melting and oblique metal evaporation (see details in another abstract). The partially melted imprinted gratings were coated with metal by oblique angle evaporation at an angle of 20˚, leaving 20-25 nm openings in the metal (Fig. 1a). ICP etching in oxygen and fluorine plasmas is used sequentially to transfer patterns to the oxide layer (Fig 1b,c). After removing the Cr and underlying photoresist, ICP etching in chlorine transfers the patterns from oxide into Si, producing high aspect ratio nano-trenches with a depth exceeding 700 nm and a top trench width of ~22 nm (Fig. 1d). After removing the remaining oxide mask, SOD material is spin-coated into the high aspect ratio silicon nano-trenches and the sample is cured in an oxygen atmosphere at 800˚C. The sample is then prepared by focused ion beam (FIB) for cross sectional TEM. Cross section TEM images (Fig. 2) clearly show void-free filling of PSZ SOD material into 22 nm wide silicon nano-trenches with an aspect ratio of ~33. The filling is flawless, even in the bottoms of the nano-trenches (Fig. 2d). The outlined process enables quick, simple and uniform fabrication of ultrahigh-aspect ratio Si nano-trenches over large areas. These nano-trenches are used here to evaluate high-aspect ratio gap filling property of SOD for 22 nm fabrication node, but can be used in other applications requiring such high density high aspect ratio trenches.

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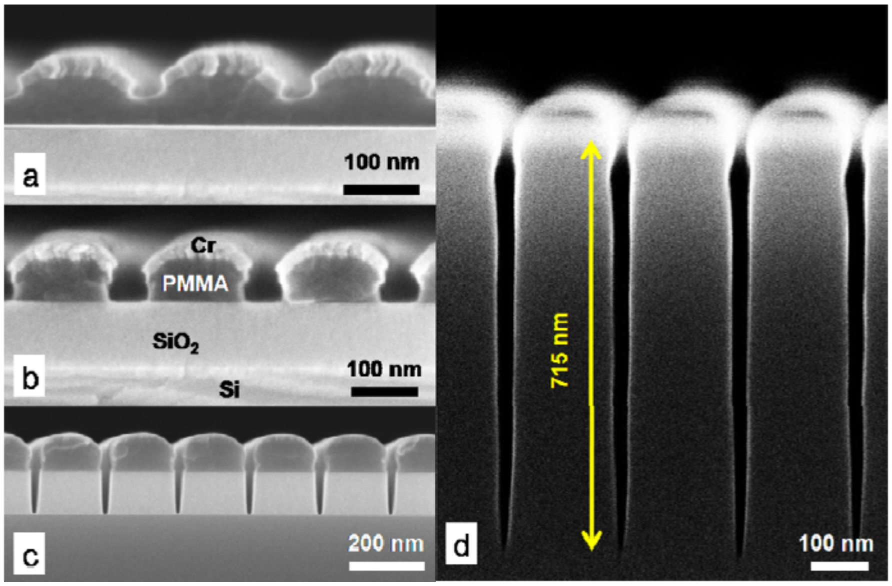

Fig. 1: (a) SEM cross-sectional image of imprinted, heat-treated PMMA gratings selectively coated with Cr; (b)the same patterns after ICP oxygen etch; (c)patterns transferred to the underlying oxide by ICP etch in C_4F_8, CHF_3, and Ar; (d) pattern transfer to silicon by ICP chlorine etch.

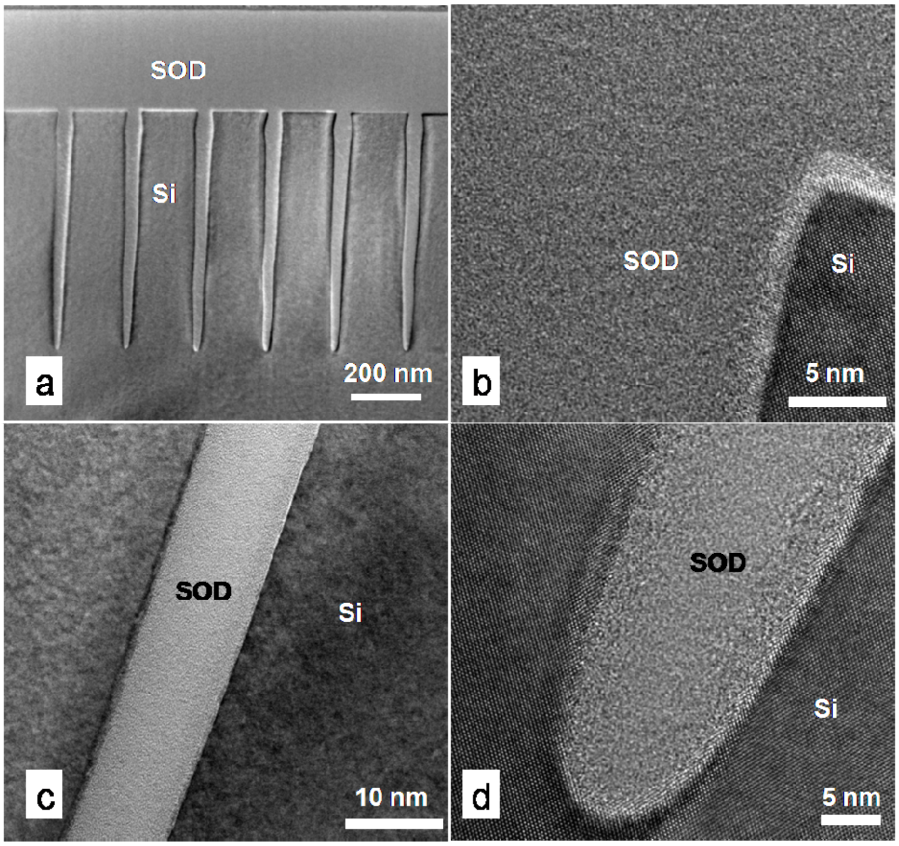

Fig. 2: TEM images of (a) an overview of the silicon nano-trenches coated with SOD, (b) the top of the nano-trench, (c) the middle of a nano-trench, and (d) the bottom of a nano-trench.