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Pattern Transfer of Sub-20nm Features with Gas-Chopping in an ICP Reactor

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Etching of Si surfaces using halogen plasmas is a central process in the microstructuring of semiconductors. There has been an extensive effort over the past decade to develop nanoelectronic devices, Nano Electro Mechanical Systems (NEMS) and templates with nanoscale resolution for Nano Imprint Lithography (NIL). The dry etching process must fulfil a number of requirements: it must have etch profile and selectivity control with respect to the underlayer and mask, cause no significant substrate damage, and yield high etching rates. The principal difficulty in meeting these requirements is the absence of a simple relationship between the process objectives and process variables (e.g., power, pressure, gas mixture, flow).

Here, we investigate sub-20nm pattern transfer into silicon with high aspect ratio by employing fluorine containing etch chemistries, where the general problem is the control of the anisotropy and CD. A large body of work has been collected on anisotropic plasma etching of Si which has focused primarily on processes employing ion-bombardment-driven Cl and Br chemistry, and the understanding of related mechanisms. However, the highly energetic particles involved induce complications due to radiation damage, undercutting, and contamination. The fact that fluorine reacts spontaneously with Si is advantageous because no high-energy ion bombardment is necessary (low lattice damage). On other hand, this spontaneous reaction makes anisotropy control difficult. Thus, one of the most important variables is the choice of the sidewall passivation reactants, also referred to as the “passivation chemistry.”

The gas-chopping technique is capable of controlling the anisotropy by alternating steps of sidewall passivation with etching, and, in combination with an ICP reactor, offers us the unique opportunity to control, almost independently, the energy and the density of the ion and neutral flux, with minimum overlap between the etching and passivation steps as the precursors are switched. Consequently, gas-chopping has become one of the most important processes for MEMS fabrication. However, the use of this technology to pattern high aspect ratio, anisotropically etched, sub- 20 nm features in silicon has proven problematic because of the “scalloping” effect on the feature sidewalls. Dense features present additional problems, both in etching and lithography. We have therefore focused this work on understanding the performance of gas-chopping etching processes for the transfer of nanofeatures.

We have optimised the gas-chopping mehtod by systematically investigating the sidewall surface roughness response (so that we minimize sidewall scallops) to produce the optimum process “recipe.” In this study, we describe a technique used to generate vertical sidewalls and negligible scallops (1-2 nm) in silicon features as small as 20 nm with an aspect ratio of 20. As a sidewall passivation precursor we use a gas mixture, which contains carbon, fluorine and hydrogen. Figs. 1-4 show that using gas-chopping, with the proper sidewall passivants and recipe optimisation, the quality of the pattern transfer approaches the limits of the initial lithography.

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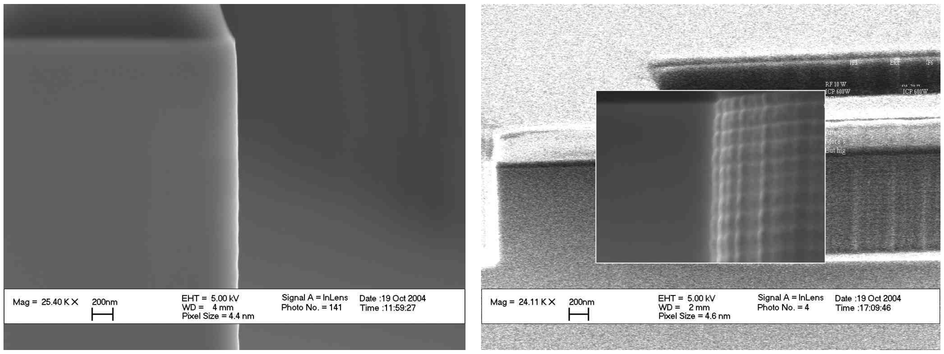

Fig. 1 By achieving a proper balance between etching step, deposition step and the "no plasma" inter-step it is possible to reduce significantly the sidewall roughness.

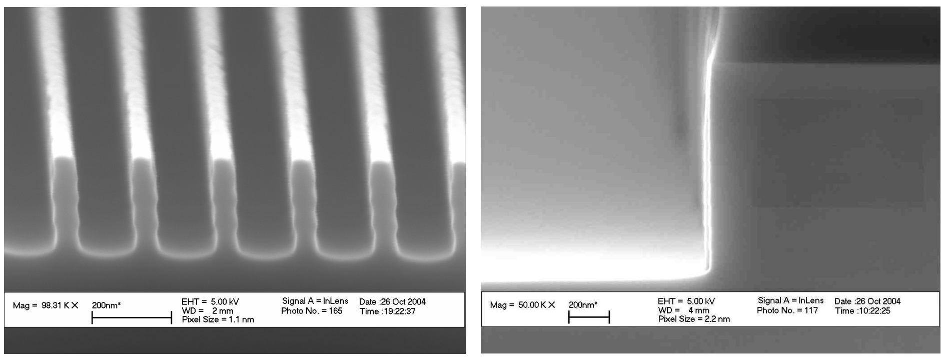

Fig. 2 The scallops formed by the gas-chopping etch are in the range of 1 to 5 nm in depth.

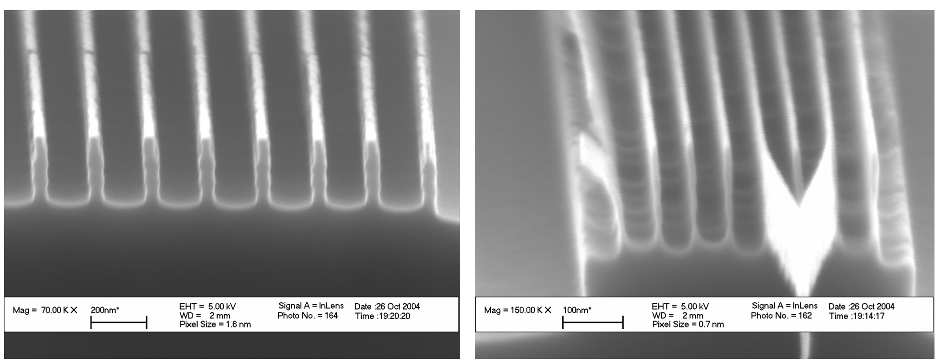

Fig.3. 50 nm (left) and 10 nm (right) width, 200 nm high features etched in Si using e-beam pattered HSQ as a mask. Etching step: 6 sec, DC = -150 V, 8 mTorr. Passivation step: 10sec DC = -80V, 35 mTorr.

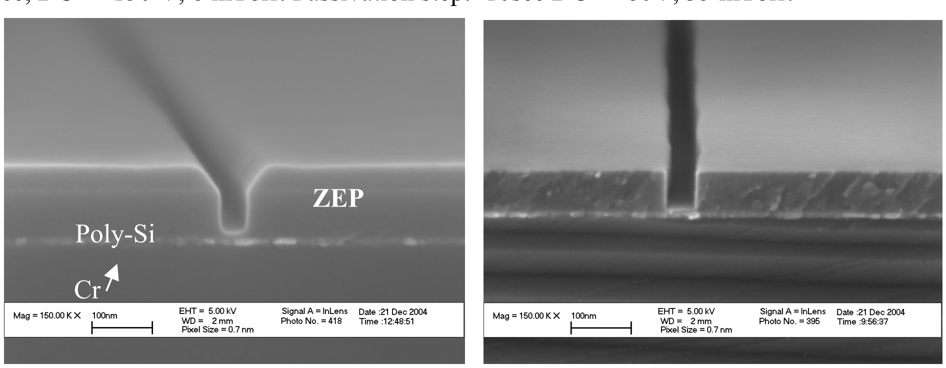

Fig. 4. 40 nm line etched in poly-Si using E-beam patterned ZEP-520. Sidewall ripples are undetectable and there is no noticeable CD loss. ZEP has shrunk away from line due to SEM damage (left), ZEP removed (right).