Investigation of surface reactions in ArF photoresist by using Parallel Plate structure in conjunction with numerical analysis

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1 Introduction

Predictive modeling for resist profiles and etched-pattern profiles is one of the bottlenecks in semiconductor process simulation. Accurate reaction models for chemically amplified resists (CAR), which include surface modifications such as line edge roughness, are needed and must be capable of correctly predicting three-dimensional resist patterns. Photoresist patterns must be evaluated with respect to precise critical dimension (CD) and their etch resistance. Because of the increasing importance of polymer-size effects on the control of CD including line edge roughness and line width variation, there is a growing need for resist studies based on mesoscopic models and stochastic modeling. Although the algorithms for modeling of plasma etching seem to be mature, the capability of quantitative prediction strongly depends on the fundamental physical, chemical data of surface reactions [1]. This concerns especially to the lack of radical kinetic data. In our research we investigated radicals kinetic behavior related to surface reactions in ArF photoresist (PR) by using parallel plate structure supported by numerical analysis.

2 Experimental and numerical approach

Using parallel plate structure (Pallet for Plasma Evaluation: PAPE [2]) with ArF photoresist on the both plates (Si wafer) schematically shown on Fig. 1. We have performed the PR etching by H_2 plasma in a ICP etch reactor. We have used a high density radical source (HDRS) which allows to investigate the effect of radicals (separately from ions and photons) on the surface reaction. Practical experiment has been followed by numerical analysis using a custom made software application in order to provide better understanding of experimental results. Using Monte Carlo approach incorporating stochastic processes based on the Bernoulli scheme, we have performed simulation of radical behavior in the setup shown in Fig. 1.

3 Results and conclusions

PR thickness profile after etching on the bottom wafer is shown on Fig. 2, whereas that on the parallel plate is shown on Fig. 3. PR (210 nm thickness) is completely removed on exposed (uncovered by parallel plate) area of the bottom wafer. This is mainly due to direct incoming radical flux. Situation is dramatically changed on the region shadowed by parallel plate where only 11-nm PR layer has been etched. In this area direct flux is limited and etching is mainly done by re-emitted radicals schematically shown on Fig. 4 [3, 4]. Between exposed and shadowed areas transition region can be observed. It was revealed that this region was influenced by the decaying number of direct radical flux and the presence of re-emitted radical flux.

Etched PR thickness profile on the parallel plate is not linear and has the maximum value of 30 nm on the edge adjacent to exposed area. It goes down to the minimum value of 10 nm close to the right wall. PR thickness profile (corresponds to profile of stuck re-emitted radicals) can be approximated by quadric function. Direct flux for the parallel plate is reduced to zero and etching is done only by re-emitted radicals, thus etching in this area strictly depends on radicals sticking coefficient (SC) value. We obtained matching of measured and simulated radical stuck profiles when sticking coefficient was set to 0.2. Simulation reveals (Table 1) that in these conditions approximately 8% of total number of radicals reaches the parallel plate through re-emission and only 2% radicals take part in etching in this region.

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[2] S. Uchida et al., Jpn. J. Appl. Phys. 47, 3621 (2008).
[3] Sentaurus Topography 3D User Guide, Version E-2010.12, December 2010.
[4] J. Li, Ph.D. thesis, Stanford University, Stanford, CA, USA, March 1996.

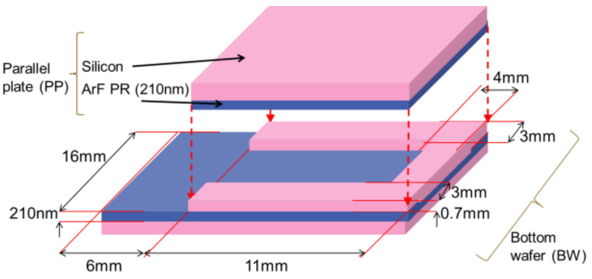

Fig. 1 Schematic view of PAPE structure.

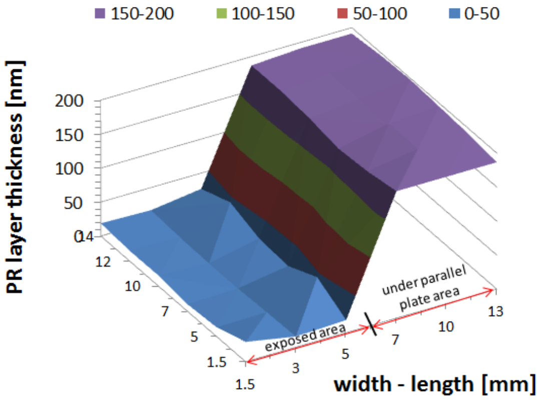

Fig. 2 ArF PR thickness distribution on the bottom wafer.

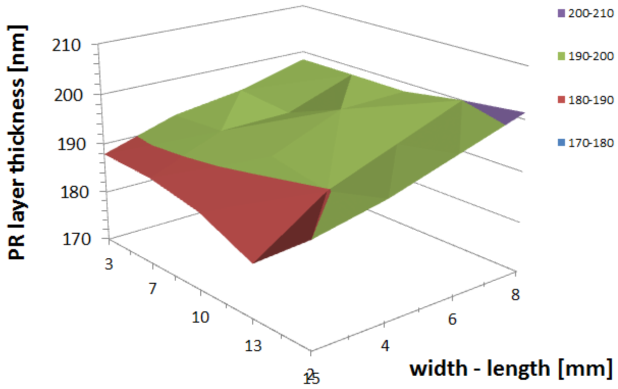

Fig. 3 ArF PR thickness distribution on the parallel plate.

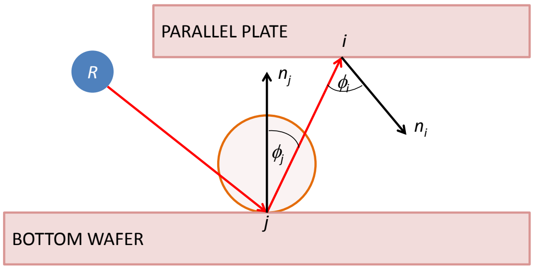

Fig. 4 Radical re-emission mechanism.

Table 1 Parameters describing radicals movement in PAPE structure (percentage scale).

Number of radicals considered	10^7
SC bottom wafer	0.2
SC parallel plate	0.2
Radicals didn't enter PAPE	11.7
Radicals left PAPE	44.3
Hits of parallel plate	8.3
Hits of the bottom wafer	52.4
Radicals stuck on the bottom wafer	41.9
Radicals stuck on the parallel plate	2.1