Analysis of Coulomb and Johnsen-Rahbek Electrostatic Chuck Performance for EUV Lithography

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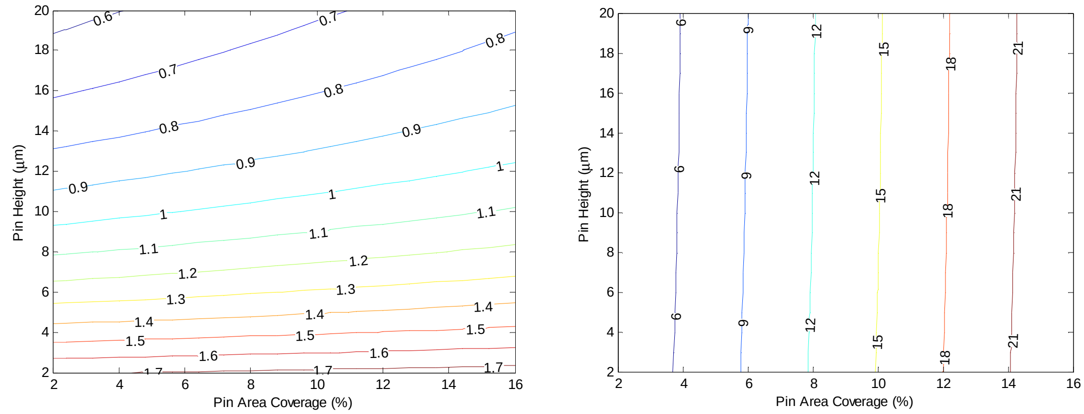
The successful implementation of extreme ultraviolet lithography (EUVL) requires the use of an electrostatic chuck to both support and flatten the mask during scanning exposure. The EUVL Mask and Chucking Standards, SEMI P37 and P40, specify the nonflatness of the mask frontside and backside, as well as the chucking surface, to be no more than 50 nm peak-to-valley (P-V). Thus, characterizing and predicting the capability of the electrostatic chuck to reduce mask nonflatness to meet this specification are critical issues.

Using finite element (FE) techniques, numerical models of Coulombic and Johnsen-Rahbek (J-R) electrostatic chucks have been constructed and evaluated for their clamping performance. The models include the effects of reticle and chuck nonflatness, surface friction, and the finite stiffness of the chuck. We have also studied the influence of the material properties on the chuck's performance, in particular the dielectric constant and, in the case of the J-R chuck, the finite resistivity. The properties of a chuck designed to clamp a reticle for EUV lithography are described in detail.

Much of the Coulombic electrostatic chuck model has been described in earlier publications. In this paper, for the first time, the governing equation identifying the force-gap relationship for a J-R chuck is derived and compared to the Coulombic response. Figure 1 illustrates typical design curves that have been generated for the two chucks. In each case, the applied voltage was 400 V and typical dimensions and material properties were used (see Fig. 1 caption). For the nominal parameters assumed, the J-R chuck can achieve a significantly higher chucking pressure.

It should be noted that the design curve for the J-R chuck (Fig. 1b) used $\rho_c / \rho_v = 100$. Here, ρ_v denotes the electrical resistivity of the chuck substrate, and ρ_c represents the resistivity of the thin contact layer at the interface between the chuck and the reticle. Figure 2 shows the clamping force of a J-R chuck as a function of the ratio ρ_c / ρ_v, considering a contact layer thickness of 1.0 µm and a dielectric thickness of 250 µm. In practice, $\rho_c >> \rho_v$, thus J-R chucks are able to achieve relatively strong electrostatic clamping forces. As the ratio ρ_c / ρ_v approaches 1.0, the clamping force approaches that of a Coulombic chuck.

To illustrate the clamping performance of the Coulombic and J-R chucks, FE models were used to simulate the electrostatic chucking of a reticle having uniform thickness and an initial P-V nonflatness of 1101 nm (see Fig. 3). The simulations predicted the final pattern surface flatness for each type of chuck using a pin height of 10 µm with area coverage of approximately 8%. Consequently, Fig. 1 shows the average clamping pressure generated on the Coulombic chuck was 1.0 kPa, whereas the J-R was 12.0 kPa. Figures 4a and 4b are out-of-plane distortion (OPD) plots of the pattern surface of the mask after clamping, depicting a P-V nonflatness of 72 nm on the Coulombic and 34 nm on the J-R chucks, respectively. Modeling predictions such as these are presented in the paper for a range of design parameters for the two types of chucks. These results, which provide the first comprehensive comparison of Coulombic and J-R chucks, are currently being used to establish specifications for chuck geometry and to identify the range of flatness variations that can be accommodated with electrostatic chucking.



(a) (b)

Fig. 1. Average clamping pressure (in kPa) for the (a) Coulombic chuck for 400 V, dielectric constant = 8, dielectric thickness = 150 µm, and (b) J-R chuck for 400 V, dielectric constant = 8, dielectric thickness = 250 µm, and $\rho_c / \rho_v = 100$.

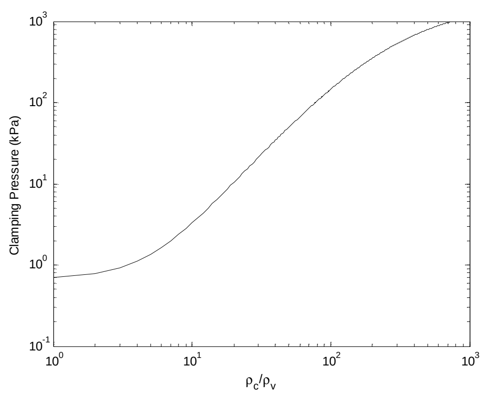


Fig. 2. J-R electrostatic pressure vs. resistivity (dielectric constant = 8 at 400 V).

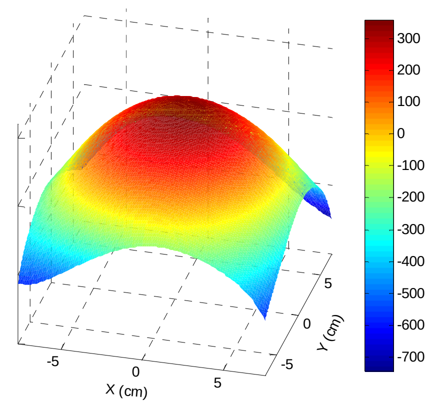
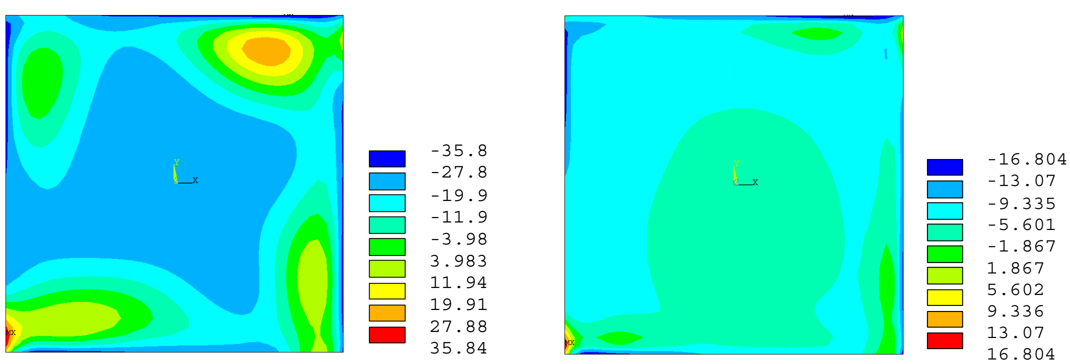


Fig. 3. Initial reticle surface nonflatness for the FE model, P-V is 1101 nm. (Scale in nm).



(a) (b)

Fig. 4. OPD contours showing final shape of the reticle pattern surface when chucked on the (a) Coulombic chuck (P-V of 72 nm) and (b) J-R chuck (P-V of 34 nm). (Scales in nm.)