Sub-20nm node photomask cleaning enhanced by controlling zeta potential

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Zeta potential, a measure of the electrostatic forces between contaminating particles and photomask surfaces, can be used to improve particle removal efficiency.

As semiconductor manufacturing advances to sub-20nm node (i.e., minimum feature pitch) technology, specifications with respect to ‘dust’ on photomasks are becoming ever more stringent. Photomask cleanliness is essential to high-quality lithography, and flaws seriously affect manufacturing cycle time and productivity. For example, detecting a single newly introduced particle following pellicle (protective cover) mounting results in a loss of one to two days for demounting, repair, and cleaning. A major challenge in developing sub-20nm node mask cleaning processes is removing extremely fine particles (<50nm) from the mask surface. In the past, we have attempted to adjust the nozzle flow and spray force (physical force), but improvement is limited and the method damages the mask pattern. We have also tried increasing the concentration of the cleaning chemical (chemical force), which degrades the photomask film.

Here, we describe an alternative mask-cleaning method based on chemical force induced by so-called zeta potential (ZP). Extremely fine contaminating particles derive mostly from the deionized water used in chip fabrication and from cleaning-tool piping. Whether a particle adsorbs onto a mask surface in chemical solution depends on the balance between van der Waals and electrostatic interactions. Van der Waals interactions increase as two surfaces get closer to each other. In contrast, electrostatic interactions result from the electrical potential, or ZP, between the mask and particle surfaces. The behavior of ZP is determined by chemical properties such as pH, electrolyte concentration, and surface energy. As shown in Figure 1, the chemical force between particles and the mask surface changes in different ZP environments.

The charge on the surfaces disturbs the local distribution of ions (charged molecules) and leads to the formation of an electrical double layer (see Figure 2). The ZP at the junction of the fixed (surface) layer and the diffusion (neighboring) layer can be measured by electrophoresis, which uses an applied electric field to separate ions. In this work, we used electrophoresis to measure the ZP between standard Si₃N₄ (silicon nitride) particles and a quartz surface. We defined the velocity of electro-osmotic flow \( v \) as Function 1,

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v = \mu E
\]

where \( \mu \) is electro-osmotic mobility, which we defined in turn as Function 2,

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\mu = \varepsilon \zeta / \eta
\]

where \( \eta \) is the sample viscosity and \( \varepsilon \) is the dielectric constant. Generally, the ZP (\( \zeta \)) can be calculated from the measured velocity of the electro-osmotic flow.

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Currently, the most widely used substrate for sub-20nm advanced masks is OMOG (opaque molybdenum silicon on glass), which is mostly quartz. The OMOG mask substrate surface is easily negatively charged during cleaning, and we created an alkaline environment to negatively charge the Si$_3$N$_4$ particle surfaces, resulting in electrostatic repulsion between the particles and the substrate. At the nanoscale, stronger repulsion means easier removal of particles. By controlling the ZP of different proprietary chemicals in the cleaning process from –15.2 to –96.2mV, and separating the Si$_3$N$_4$ particles according to size, we observed a total improved removal efficiency (PRE) for Si$_3$N$_4$ particles (40–200nm) of about 6.2% from baseline, and of the PRE for extremely fine particles (40–80nm) of 17.3% (from –18.8 to –1.5 as we increased ZP to –96.2 from –15.2). Table 1 summarizes the PRE for various chemicals under different ZP conditions.

Theoretically, ZP indicates the repulsing force between particles and mask surfaces. In this study, the PRE is highly correlated with the ZP of the cleaning chemical. A stronger ZP leads to a better PRE. Consequently, ZP is helpful in evaluating the performance of new chemicals for mask cleaning. Note that to enhance photomask cleaning for sub-20nm nodes, the chemical force must be increased because the physical force has been constrained to avoid pattern damage. Choosing a suitable cleaning process for next-generation mask cleaning is a matter of great urgency. Chemicals play an important role in the cleaning process, and ZP is a powerful index for evaluating the potential of new chemicals for this purpose. As a next step, we plan to continue our investigations with an eye to using ZP to select the best chemicals for mask cleaning.
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