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Evaluation of protection schemes for extreme ultraviolet lithography (EUVL) masks against top–down aerosol flow

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Abstract

Extreme ultraviolet lithography (EUVL) is considered as the next generation lithography for 32-nm-node or smaller in semiconductor manufacturing. One of the challenges is to protect the EUVL masks against particle contamination, due to the unavailability of conventional pellicles. In this study, the EUVL mask protection schemes of Asbach et al. (2006. Technical note: Concepts for protection of EUVL masks from particle contamination. *Journal of Nanoparticle Research*, *8*, 705–708), who proposed to mount the mask upside-down, have a cover plate with particle trap and apply phoretic forces, were evaluated against top–down aerosol at atmospheric pressure. Experimental evaluation was performed using 150 mm wafers as witness plates, and PSL particles ranging from 125 to 700 nm. For the numerical assessment of the protection schemes against particles between 10 and 3000 nm, a statistical method using a Lagrangian particle tracking simulation tool was employed to calculate the deposition velocity. It was shown that the critical surface could effectively be protected against top–down aerosol.

Keywords: EUVL; Mask protection; Mask carrier; Deposition velocity; Lagrangian particle tracking

1. Introduction

Extreme ultraviolet lithography (EUVL) is a strong candidate for the next lithography technology generation to achieve 32 nm nodes or smaller by utilizing a light of 13.4 nm wavelength (Gullikson, Tejnil, Liang, & Stivers, 2004; Hamamoto et al., 2005; Kim, Chang et al., 2006; Yan, He, Ma, & Orvek, 2006). Every EUVL mask must be assured of being free of particles prior to scanning exposure. The mask is contained in a mask carrier during storage or shipping, and can be transported by an automated material handling system (AMHS) during integrated circuit (IC) manufacturing process. Particles can be generated at any stages of robotic handling, storage and shipping, and may deposit on the mask. A pellicle covering the critical surface of the mask has conventionally been used to protect the optical lithography mask. The mechanism of pellicle protection is to let incoming particles deposit on the pellicle but not on the critical

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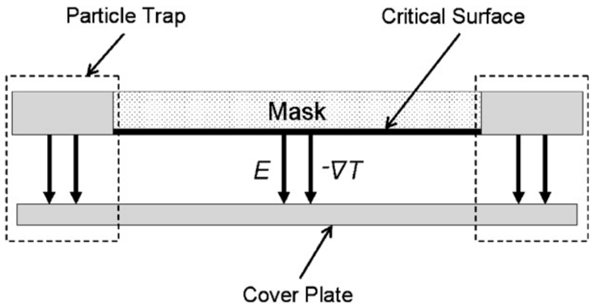

Fig. 1. Concepts of protection schemes for EUVL masks against particle contamination, proposed by Asbach et al. (2006).

surface. Since the particles deposited on the pellicle are away from the focal plane, they do not degrade the quality of the features printed on wafers. The challenge, however, is that conventional pellicles cannot be used in the EUVL technology because of high absorption of EUV radiation in the pellicles. As a substitute, it was proposed to use a removable pellicle during all stages of mask handling, shipping and storage except for the scanning exposure in a process chamber (Diefendorff, 2000; Hector & Mangat, 2001; Litt, Hector, & Seidel, 2003). When the pellicle is removed for scanning exposure at low pressure, the EUVL masks may be protected using electrostatic fields (Moors & Heerens, 2002), thermophoresis (Asbach, Pui, Kim, Yook, & Fissan, 2005; Asbach, Kim, Yook, Pui, & Fissan, 2005; Dedrick, Beyer, Rader, Klebanoff, & Leung, 2005; Kim, Fissan, Asbach, Yook, Pui et al., 2006), or reverse flow to decelerate the particles coming towards the critical surface (Kim, Fissan, Asbach, Yook, Wang et al., 2006).

Motivated by the removable pellicle concept, Asbach, Fissan, Kim, Yook, and Pui (2006) suggested EUVL mask protection schemes using a cover plate and particle trap (see Fig. 1). The EUVL mask can be mounted with its critical surface facing down. The face-down mounting is effective in lowering the contamination level at both vacuum and atmospheric pressures, with the use of gravitational settling of particles (Kim, Asbach et al., 2005; Yook et al., 2006). A cover plate can be located under the critical surface of the mask with a certain gap distance. This cover plate approach physically reduces the risk volume, which is defined as the spatial domain from where particles can potentially reach the critical surface and contribute to mask contamination. An electric field and/or thermal gradient can be established to repel the particles away from the critical surface. The safety level of the critical surface can be enhanced with a particle trap by making the particles, which are transported from the side, deposit within the particle trap before they enter the risk volume. Electrophoresis and/or thermophoresis can also be applied within the particle trap, for the protection against not only the particles entering from the side but also those generated within the particle trap.

When the mask and cover plate system shown in Fig. 1 moves horizontally by the AMHS in a clean room including a load-lock area or if there is any leakage on a side of the mask carrier, contaminant particles may be transported into the risk volume by an air flow from the side. Evaluations on the EUVL mask protection schemes against particles injected from the side were performed experimentally by Yook et al. (2006) and numerically by Engelke et al. (2007). It was shown that the face-down critical surface could effectively be protected at atmospheric pressure against the side-injected particles by applying electrophoresis or thermophoresis between the critical surface and the cover plate and additionally by having enough particle trap area. The protection with electrophoresis within the gap between the critical surface and the cover plate, however, may be counterproductive due to a generally bipolar charge distribution of particles in reality. In other words, some particles with unwanted polarity could be attracted by the critical surface. It was therefore proposed in the case of electrophoretic protection to apply a high electric field only in the particle trap, sufficient to collect all the side-injected particles of any polarity within the particle trap.

If the mask and cover plate system shown in Fig. 1 is stationary or vertically moves during automated handling by the AMHS in the clean room including the load-lock area, particles in the space above the mask, if present, can be transported from the top due to the unidirectional clean room air flow. In the presence of any vertical leakage in the mask carrier, particles can also be transported from the top. In the case of the top–down aerosol flow, flow pattern near the mask and cover plate system is much different from that of the previously studied side-injected aerosol. The main objective of this study is therefore to evaluate the protection schemes, which have been proposed by Asbach et al. (2006), against the top–down aerosol at atmospheric pressure.