Improving lithography pattern fidelity and line-edge roughness by reducing laser speckle

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ABSTRACT:

Continued progress of 193nm optical lithography has enabled CMOS device scaling down to the 32nm node using immersion lithography, double-exposure and double-patterning techniques. Although the increasing transistor densities and device performance continue to lead to higher levels of device functionality, controlling the transistor-level variability due to geometric errors of the patterning process is becoming more difficult. The contribution of line-edge and line-width roughness (LWR) to CD uniformity is an increasing concern. The focus of prior studies on the sources of LWR has considered resist, process and image contrast effects. However, little work has been reported on the characteristics of the illumination which also impact the pattern fidelity.

In this paper we present a detailed study of the impact of coherence, or laser speckle, of current-generation 193nm Argon Fluoride (ArF) excimer sources on lithographic patterning. We also propose methods to improve CD uniformity and LWR by modification of the coherence of the illumination source.

We have developed a new metrology capability (Figure 1) to characterize the single-pulse speckle patterns at the exit of the laser aperture (Figure 2) and have quantified the speckle dependence on time integral square (TIS) pulse-duration for different system configurations. The TIS is obtained from the temporal profile of the laser pulse and can be strongly modulated by optical pulse stretching (OPuS). We have performed lithographic exposures as a function of pulse-duration of the source and have quantified the speckle impacts on measured photoresist LWR using immersion and dry lithography processes. Measurements were obtained for multiple feature sizes, pitches and illumination modes using both static and scanning exposure. We compare the measured LWR due to laser speckle (Figure 3) to results of an LWR image model, which accounts for the edge-roughness and CD uniformity due to the effective dose variation from laser speckle. The model allows parameterized input of speckle grain size and contrast, or direct input of actual measured speckle maps. Finally, we present measurements that demonstrate the proportionality between speckle contrast and the inverse root of the time integral square (TIS) pulse-duration, namely, $contrast_{speckle} \propto \frac{1}{\sqrt{TIS}}$, and we find that the lithographic LWR exhibits a similar relationship with pulse-duration. The requirements for next generation lithography exposure systems are considered and various means to improve pattern fidelity, LWR and CD uniformity by modification of the illumination coherence are discussed.

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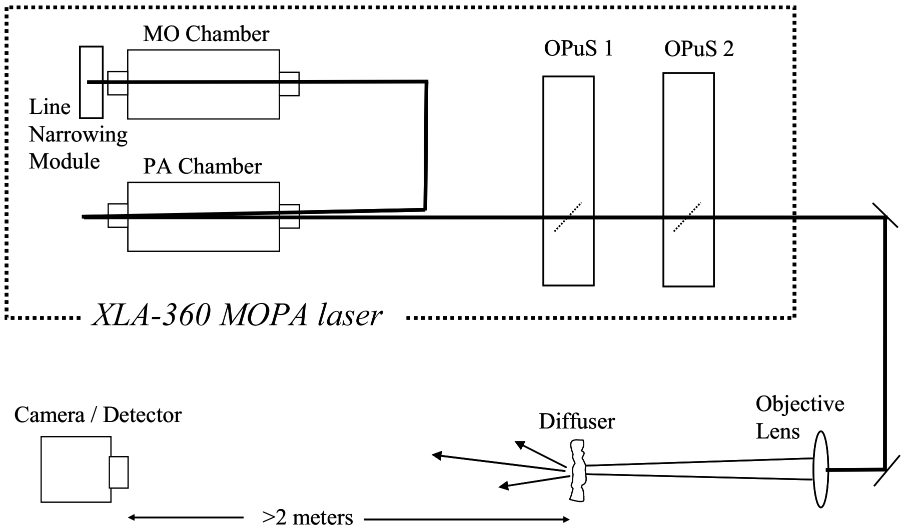

Figure 1. Schematic of speckle measurement setup

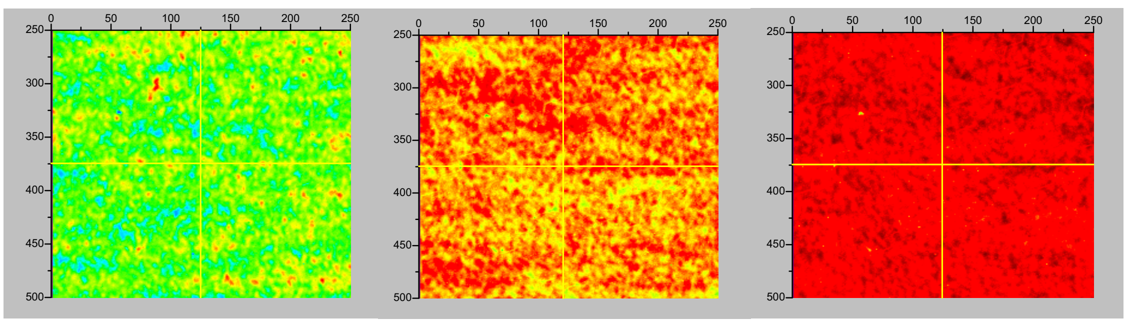

Figure 2. Measured single-pulse laser speckle as a function of increasing pulse duration; speckle contrast is 16%, 9% and 6% for the images from left to right

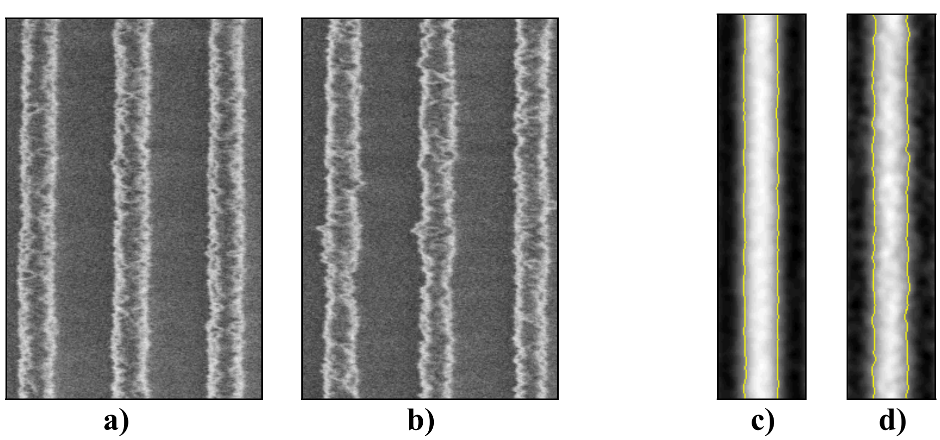

Figure 3. SEM (symmetric magnification, 1μm FOV) of photoreist line-space pattern imaged using 1.2NA immersion lithography for a) standard pulse-stretching and b) short-duration pulse. The modeled photoresist edge contours due to 1% speckle contrast and 2% speckle contrast are shown in c) and d) respectively

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