Influence of shield roughness on Mo/Si defect density for extreme ultraviolet lithography mask blanks

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The authors investigated the influence of surface roughness of stainless-steel shields in an ion beam sputtering chamber on the particle defect density of deposited 50 pairs of Mo/Si bilayer films (Mo/Si)50 used in extreme ultraviolet mask blanks. Shells with varying arithmetic average surface roughness (Ra range approximately 3 to 20 μm) were mounted close to the sputtering targets and the substrate, and along the vacuum chamber interior wall. Silicon-rich particles (Si and Si/Mo) with diameters in the range of several tens of nanometers or more were quantified within a 142 mm × 142 mm area of the prepared blank film using a mask blank inspection tool. Si-rich particle defect density was found to be proportional to the inverse square of the shield surface roughness, suggesting that Si-rich particles arise from the shield surface. The shells with roughness exceeding 8 μm effectively suppressed the accumulation of Si-rich particle defects on the blank film. © 2013 American Vacuum Society. [http://dx.doi.org/10.1116/1.4813776]

I. INTRODUCTION

Extreme ultraviolet (EUV) lithography using a 13.5-nm EUV light source is an emerging lithography technology for 32-nm half-pitch nodes and beyond. Because EUV light is absorbed by many materials, EUV lithography requires the traditional transmissive mask blank with a reflective mask blank. EUV mask blanks are comprised of multilayered molybdenum/silicon (Mo/Si) deposited on a glass substrate. Maximum EUV light reflectivity critically depends on the thicknesses of the Mo and Si layers; hence, these thicknesses must be precisely controlled. Thin films for electronic devices are conventionally fabricated by magnetron sputtering deposition in which film thickness is controlled by a mechanical metal shutter placed between the sputtering target and the substrate. Therefore, some of the sputtered materials heading toward the substrate from the target are intercepted by the shutter. Eventually, the substrate surface may be contaminated because of defects from the film deposited on the shutter.

When fabricating the film for the EUV mask blank, nanometer-scale surface defects on the film, such as particles, have been reported to cause aberrations in the resist and consequent malfunctioning of the semiconductor chip. Besides developing powerful and long-term, reliable EUV light sources, reducing defects in the EUV mask blank presents a major challenge to the commercialization of EUV lithography. In contrast to the conventional magnetron sputtering process, ion beam sputtering is performed with an Ar+ ion beam (approximately 180 nm diameter on the target). As the Ar+ ion beam hits the target, the sputtered target material is deposited onto the substrate. The film thickness is controlled not by a mechanical shutter but by an electronic shutter that controls the ion beam flux. Therefore, ion beam sputtering is regarded as the most suitable technique for achieving low-defect Mo/Si multilayer deposition.

However, few studies have considered the formation of particle defects on the mask blank during film growth, which is inevitable even under ion beam sputtering. Film defects fall into two major categories: (1) pit-type defects induced mainly by polishing and cleaning of the substrate and (2) bump-type defects generated during sample handling and film deposition. To reduce particle defects in the Mo/Si multilayer EUV mask blank, the underlying cause of deposition-derived particle defects in the ion beam sputtering process must be identified. Equally important is quantifying the extent of the defects. In this work, we investigate the bump-type defects, including deposition particles in a deposition vacuum chamber whose internal walls are lined with roughness-controlled shields. The influences of surface roughness and mount location of the stainless-steel shield on particle defect density of the Mo/Si multilayer were quantified using a mask blank inspection tool.

II. EXPERIMENTAL PROCEDURES

A. Film deposition

Figure 1 is a schematic of the ion beam sputtering system (Veeco Instruments, Inc. Nexus Ion Beam Deposition System, 1.8 MHz RF plasma source), in which three pure metal targets (molybdenum, silicon, and ruthenium, each of diameter 301.8 mm and thickness 12.7 mm) were individually