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Fabrication of a high-resolution mask by using variable-shaped electron beam lithography with a non-chemically amplified resist and a post-exposure bake

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ABSTRACT

A high-resolution technique was developed for fabrication of photomasks for 10-nm-technology nodes and beyond. Current mask manufacturing techniques use a chemically amplified resist (CAR) photoresist material that has a complex mechanism of acid generation that obscures the criteria for selecting the polymer, quencher, and crosslinker for industrial purposes. It is therefore important to validate non-CAR materials as alternative solutions for mask fabrication. In this research, diluted ZEP520A was used as a non-CAR material in conjunction with a JBX9000 electron-beam lithography (EBL) tool. Additionally, a post-exposure bake (PEB) is normally used in mask fabrication. The PEB method was also used in this research, and we investigated its temperature dependence. Critical dimensions (CDs) of 1:1 line-and-space, isolated space, and isolated line patterns on a diluted ZEP520A resist were measured and showed CD shrinkage, an extension effect, and retention of the integrity of the shape after the PEB process. A resolution of the order of 20 nm was attained and the insights gained from optimization of the PEB process might be usefully applied in advanced methods for fabricating masks of the next generation.

1. Introduction

The 2013 edition of the International Technology Roadmap for Semiconductors sets challenging requirements for 10 nm half-pitch logic nodes in terms of subresolution feature sizes for photomasks. A high resolution of 40 nm will be required [1]. Furthermore, to develop masks of the next generation, we expect that it will be necessary to achieve greater degrees of super-resolution.

Currently, chemically amplified resists (CARs) are normally used in the manufacture of masks. CARs contain a photochemical acid generator (PAG) that produces acids that control and catalyze the dissolution of the photoresists, allowing a high sensitivity and high resolution to be achieved. However, there are concerns regarding post-coating delay stability, post-exposure delay stability, and other effects resulting from the use of the CAR material itself, including the complicated mechanism of acid generation [2]. Furthermore, there is a remaining problem of surface roughness of the patterned resists. This is referred to as line-edge roughness (LER) or line-width roughness. Understanding the details of LER is important for material and process design, and the causes of LER have been intensively investigated during the past 20 years [3,4]. Consequently, it is important to make a careful evaluation of non-CAR photoresist materials that do not include PAGs to help to ensure proper decision making and the development of more-robust acceptance criteria for alternatives to the existing CAR-based approach to mask manufacture.

We examined the fabrication of high-resolution masks by variable-shaped electron beam (VSB) lithography using a JBX9000 instrument (JEOL Ltd., Tokyo) with ZEP520A as a positive electron beam non-CAR (Zeon Corporation, Tokyo) [5]. Furthermore, as a part of our ongoing efforts to develop high-resolution fabrication techniques, we also studied the use of a post-exposure bake (PEB), a process known to cause an annealing effect for spin-coated films on glass and to suppress the proximity effect [6]. Typically, PEB is used to increase the sensitivity of resists containing CAR materials. In our researches, we applied the PEB method in mask fabrication from non-CAR resists, and we demonstrated its feasibility as a high-resolution technique.

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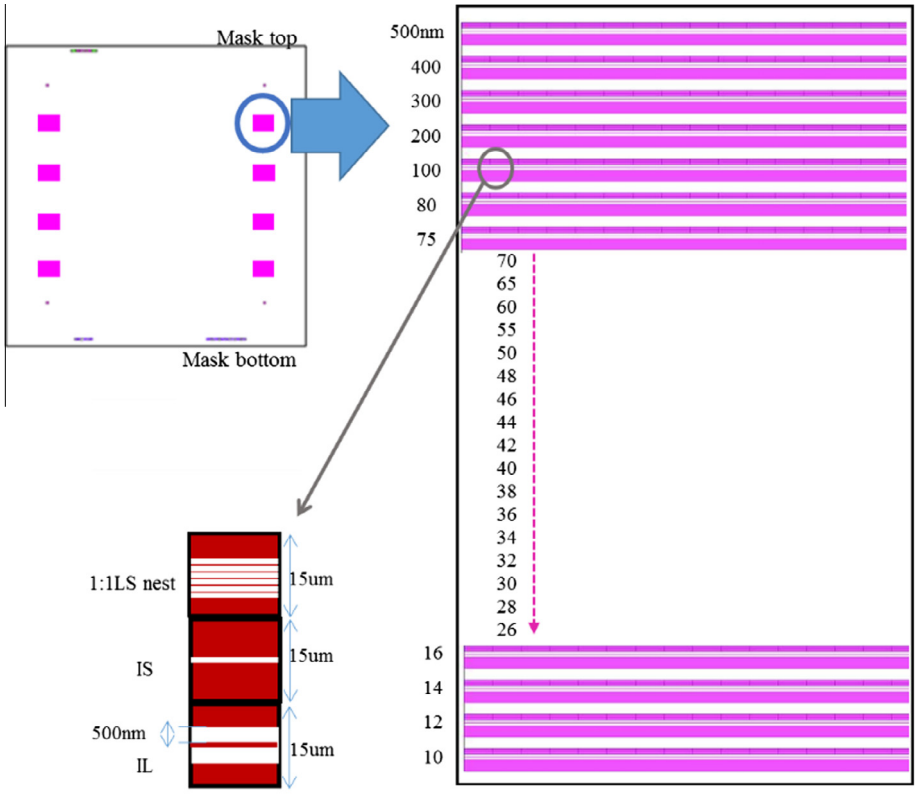

Fig. 1. Layout of the optical mask pattern.

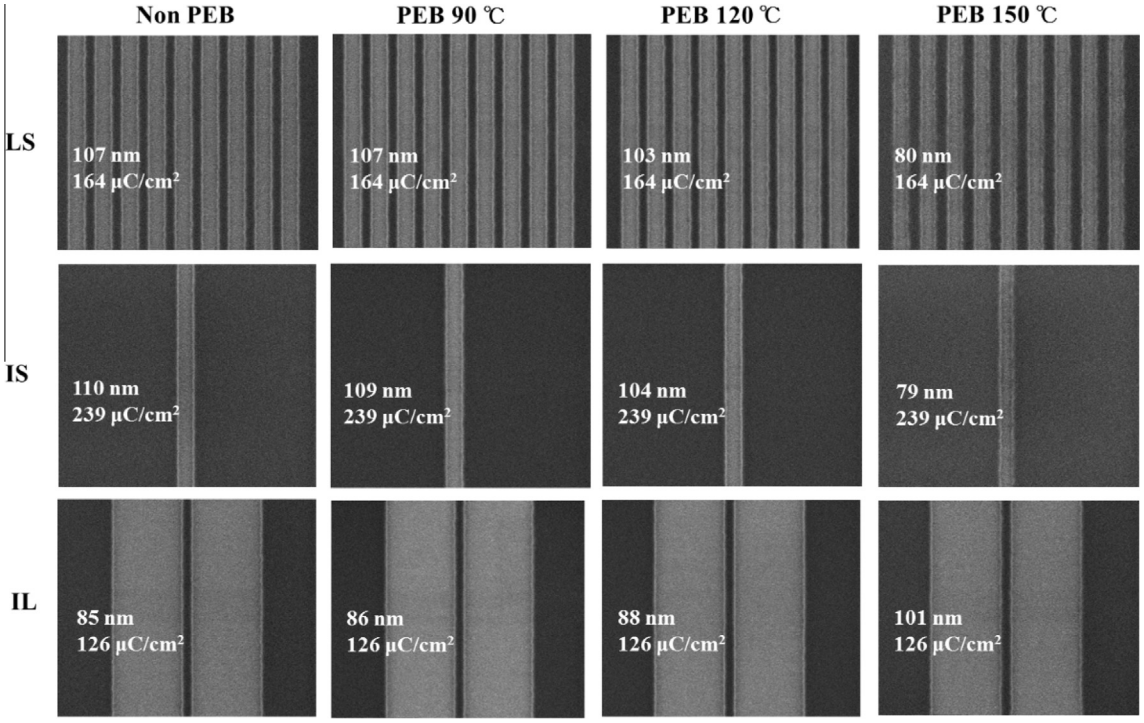

Fig. 2. Top-down SEM images showing the PEB temperature dependence for LS, IS, and IL patterns (design CD, 100 nm; magnification, 75,000×).

2. Experimental details

Quartz substrates coated with a 60-nm-thick layer of chromium were used as mask blanks. ZEP520A diluted 1:1 with ZEP-A thinner consisting of 98% methoxybenzene (anisole) was used as a non-CAR resist sample. The dilution of the resist may lead to issues regarding process stability, may affect LER and, on a whole, has the potential of being detrimental with regard to the overall