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Full Length Article

Low-cost laser printable photomask: One-step, photoresist-free, fully solution processed high-grade photolithography mask

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ABSTRACT

Owing to the short life cycle of present-day microelectronics, conventional method of photomask fabrication should be replaced in order to improve the resultant agility and productivity of photolithography. To fulfill these requirements, we suggest a fully solution-based one-step fabrication method of a high-grade photomask, without the use of a photoresist, vacuum deposition, and etching process. The photomask is fabricated via the laser-induced instantaneous thermochemical metallization of an optically catalyzed hybrid complex synthesized in-situ from a low-cost particle-free organometallic solution. This reaction yields a masking layer whose high selectivity of less than 1 μm, self-generated retroreflective structure, and excellent optical surface are comparable to those of masks fabricated by vacuum depositions. In addition, the complexity of the process is minimized owing to the solution deposition of all the constituent layers. A series of evaluations and the application of this method to an actual photolithography process confirm that this approach constitute a next-generation photomask fabrication method by satisfying both improved agility and productivity of microelectronics manufacturing.

1. Introduction

Photolithography is the most powerful technique used to fabricate micro/nano scale features used for opto-electronics, such as semiconductors, displays, optics, etc. Because of its high-throughput, excellent process reliability, wide range of applicability, and already well-defined mechanism, this method is considered far superior to imprinting and contact printing, which were considered promising alternative fabrication methods [1]. Recently, however, the life cycle of opto-electronic products has been significantly shortened and hence, the demands for replacing photolithography with more agile processes for design change have increased. The low agility of typical photolithography results from both the costly and complicated procedures required for fabricating photomasks; these photomasks fabrication is essential preparation in photolithography to make optical template to replicate a specific pattern design [2–6]. Conventional photomasks are fabricated via inefficient manners that consist of an indirect patterning process, which uses photoresist (PR) [3–6]. This indirect process inevitably requires several vacuum deposition steps and chemical processes and the use of a costly ultraviolet (UV) light system. The etching process also generates harmful and toxic pollutants. Therefore, a novel/improved method for photomask fabrication is needed in order to promote the resultant agility and productivity of the photolithography. This method may lead to increased flexibility of design change and a reduction in the time and costs required for device development.

Most studies on photomask fabrication have focused mainly on improving the resolution, but the studies do not progress no longer recently [7–10]. A few studies have focused on developing substitutive methods, such as printing and dry-etching methods [11]. Printing methods represented by inkjet printing enables to easily fabricate photomasks via the selective deposition of metallic solutions using fine nozzle and then by it is subsequently sintered [12–14]. As this method is a digital-based direct patterning process, the design can be easily changed. More importantly, the process is performed in a minimal number of production steps and without the use of expensive equipment. The patterning resolution is, however, 5–10 times lower than that of photomask fabrication method, owing to the nonlinear transfer characteristic of liquid droplets during printing [1]. In addition, insufficient agglomeration of metallic particles during sintering results in rougher and less dense masking layers than those obtained by vacuum deposition [12–15]. These problems that are also occurred in the laser sintering method of metal nanoparticle solutions make the resultant selec-

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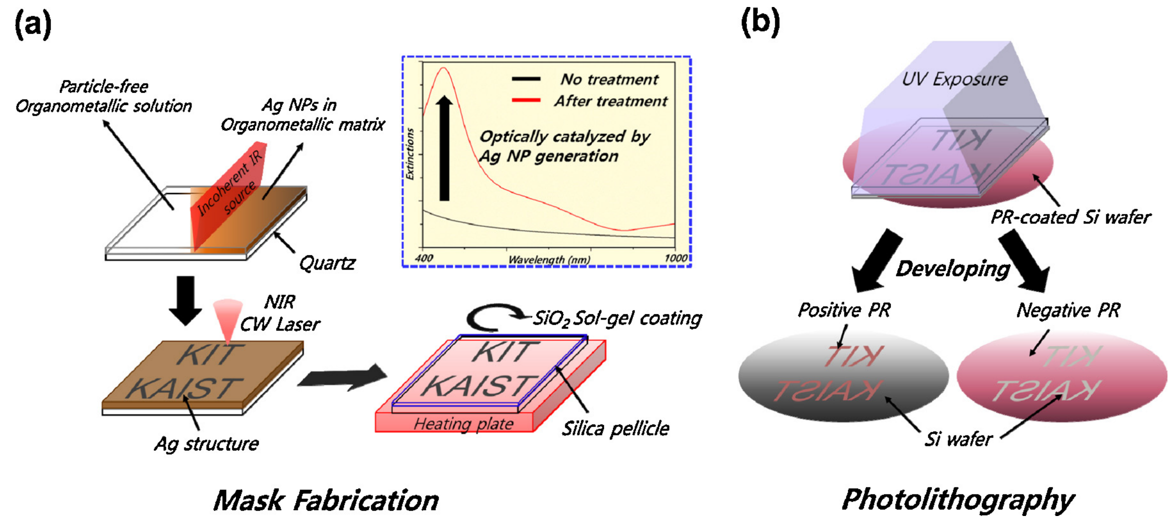

Fig. 1. Schematics of the overall process; (a) Mask fabrication: thermal treatment for generation of ultrafine photonic catalysts via a linear thermal scanning, selective irradiation of the focused laser, and spin coating of the SiO_2 precursor and baking at 250 °C. The inset shows the optical extinction of organometallic solution with respect to thermal treatment. (b) Photolithography: UV exposure of a mask attached to the PR-coated silicon wafer, and the developed positive and negative PRs on a wafer.

tivity and fidelity of photolithography process worse [16–18]. Dry etching methods, such as laser ablation technique, yield good surface quality and a densified structure. However, the typical vacuum depositions are required to form an initial masking layer and the boundary of the layer deteriorates including residuals on the substrate, owing to thermal damages induced by the intensive incident energy [2,19,20].

A digital-based one-step process, i.e., without sequential fabrication steps, may therefore be used as an alternative fabrication method for high resolution photomask. And its physical and optical characteristics of the photomask should be comparable to those of the conventionally fabricated masks.

Therefore, as shown in Fig. 1, a fully solution-based one-step method for photomask fabrication, without the need of a PR, vacuum deposition, and etching process, was developed in this study. The conventional high-grade chrome-based photomask was replaced with a silver masking layer, whose structure was optimized in order to maintain the optical properties typical of conventional photolithography. Laser-induced thermochemical reaction of an optically catalysed hybrid complex leads to direct pattern formation and a masking layer, whose high resolution and excellent optical properties are similar to those of their vacuum deposited counterparts. The complex contains ultrafine silver nanoparticles and is generated in-process, through incomplete thermal decomposition of the low-cost particle-free metallic complex solution, in order to enhance the laser absorption, as shown in Fig. 1(a) [21]. Use of a solution coating of all the constituent layers, including the masking and protection layers, minimizes the complexity of the process. In addition, the self-enhanced adhesion between the silver masking layer and the quartz substrate, which was discovered experimentally, also reduces the number of processing steps additionally required and improves the reliability. Finally, the feasibility of this mask was evaluated by the application to an actual photolithography process, as shown in Fig. 1(b).

2. Experiment

A 6-inch square quartz plate was prepared as a photomask substrate, which was cleaned by dipping in several cleaning solutions, such as distilled water, acetone, and toluene. In addition, a particle-free silver organometallic solution supported by Inktec Co. (CO-011) was deposited on the substrate, by using a spin coating method; a uniform coating was obtained by automatically controlling the rotation speed within 2000–4000 rpm. Ultrafine Ag nanocrystals were uniformly generated over the entire substrate through linear translation of a bar-shaped infrared lamp of 200 W output power. Here, the vertical distance between the light source and the substrate, heating power, and translation rate were precisely controlled, in accordance with the required thermal treatment condition such as a temperature of 90 °C for 30 s. A continuous wave (CW) ytterbium fiber laser (IPG Photonics YLM-10W) of 1070 nm wavelength was used in this study. The laser was focused to 5 μm by using an objective lens corresponding to 20 x and it was integrated with a precisely controlled 3D linear motion stage in order to realize two-dimensional motion of the laser spot. The laser process was performed under yellow light environment, and blowing N2 gas. After laser irradiation, the specimen was moved to a washing bath containing normal hexane solution; the solution was washed from the non-irradiated region. A silica sol-gel precursor (High Purity Chemicals Co.) was spun at 1500 rpm on the laser processed specimen and then it was solidified by baking for 3 min at 90 °C. The specimen was baked for an additional 20 min at a temperature above 250 °C. The fabricated specimen was examined by using optical microscope, atomic force microscope and scanning electron microscope. A stepper equipped with a Hg lamp was used on a 1:1 magnification scale because of the direct contact between the photomask and the 4-inch silicon wafer. Positive and negative PRs are L300-30 and DS-S700 of Dong-jin Co., respectively. The PR was spun on the wafer at a spinning rate of 3000 rpm for 40 s then it was baked at a temperature of 90 °C for 90 s. The coated PR was exposed by g-line (436 nm) light for 3 s and was developed. A silicon wafer was etched, by using a Bosch deep reactive ion etching method. The etching instrument (AMS200) of lcatel Co. was used. The etching behavior on the relative adjustment of exposure time (3–10 s) between SF_6 and C_4H_8 was observed using SEM measurement.

3. Results and discussion

PR, which is conventionally used in photolithography, has a high sensitivity to UV light. The wavelengths used to quantitatively characterize the light sensitivity and reactivity of PR is represented by lie within three spectra, namely i-(365 nm), h-(405 nm), and g-(436 nm) lines [3,4]. A masking layer should therefore have