Tunable-Linewidth Nanoimprint Working Stamps Fabricated by Double Oblique Metal Deposition

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ABSTRACT

Conventionally, the master stamp for nanoimprint lithography (NIL) is made of silicon by e-beam lithography when pursuing very high precision, which needs a great amount of time and cost for manufacturing. In addition, diverse applications require variable linewidths and pitches for obtaining demanded performance. This study proposes an efficient method for making working stamps with tunable linewidth using resist trimming technique, oblique metal deposition as well as reactive-ion etching process. The range of the linewidth of patterns was from 55 nm to 37 nm and the patterns were faithfully transferred to the substrates by plasma etching. By the chemical process, working stamps are efficiently manufactured and it can apply numerous categories.

Keywords: nanoimprint, oblique metal deposition, working stamp, resist trimming.

1 INTRODUCTION

Nanoimprint is an attractive technology for nano pattern fabrication because of high throughput and free from physical and chemical liminations. Plenty research articles have shown that NIL posesses extremely high resolution[1]. However, the patterns on master stamp are directly transferred to the resist film on substrates and the resolution depends on the stamp. Nanoimprint stamps are usually made by electron beam lithography (EB lithography) and reactive ion etching (RIE). Nowadays, it is still difficult to obtain nano pattern stamps with high aspect ratio and enough resolution even when the leading-edge technology applied. The master stamp is so precious that probably avoiding damages is very critical in imprint process. However, the stamp is directly imprinted on the resist in specific pressure and temperature and the damages are inevitable. Hence, a substitute for the master stamp is needed and the quality of the original is also maintained.

By replicating mastrer stamps into working stamps, the damages of the original stamps could be greatly diminished. The working stamps can be replicated from the master one by nanoimprint and RIE process in low cost and high efficience. In addition, the pattern of imprinted resist could be trimmed using plasma etching process for reducing the linewidth of structure which is fixed by stamps to possess tunable ability[2, 3]. In less than a decade, Joubert have shown the smaller critical dimensions of resist patterns could be fabricated by resist trimming exempting from traditional photo lithography[4]. For oblique metal deposition, it constantly is applied to fabricate the film with sidelong lattice for purposes of magnetism, optic and electronic characteristices[5]. Combining with resist trimming process, the patterns from the original could be tuned in different linewidth and the metallic layer would be the etching mask for transfering patterns to underneath layers by reactive ion etching (RIE)[6]. By using resist trimming, oblique metal deposition, and RIE process, tunable-linewidth nanoimprint working stamps could be succesfully fabricated with optimized the porcess parameters, e.g. plasma power, ethcing gases, deposition thicknesses, in low cost and high throughput.

2 EXPERIMENTAL SETUP

In this study, the plasma etching processes were carried out usung the commercial RIE etcher (RIE-200L, SAMCO). The process flow is shown in Fig. 1. First, silicon wafers are cleaned using standard RCA process. Second, 50 nm thick SiO_2 layer was deposited onto the silicon wafer by PECVD as the release layer of plasma etching process, which could be removed using BOE[7]. Third, nanoimprint process (Fig. 2) was applied to obtain 54 nm linewidth resist gratings with 144 nm pitch; the height was 192 nm (Fig. 3).

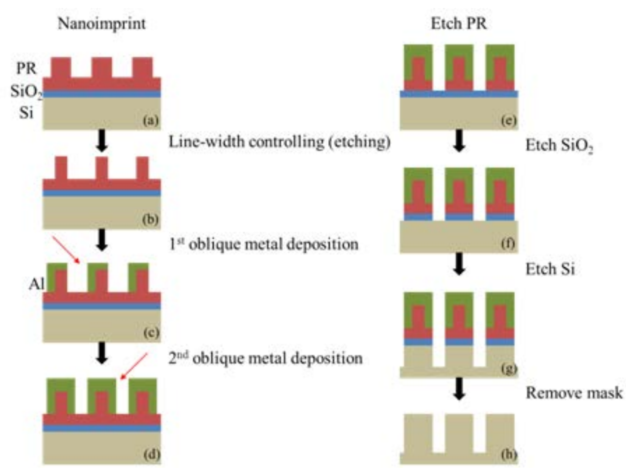

Figure 1: Scheme process flow of double oblique metal deposition technique

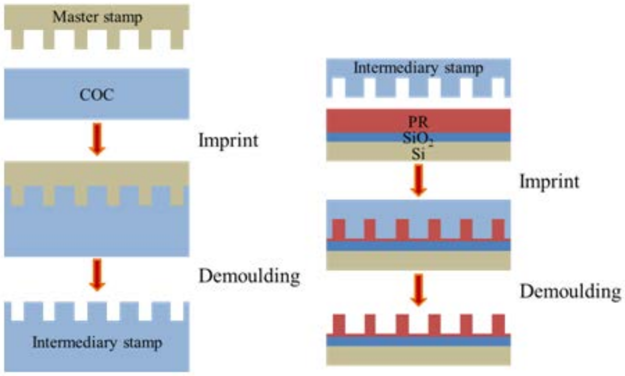

Figure 2: Scheme process flow of double oblique metal deposition technique.

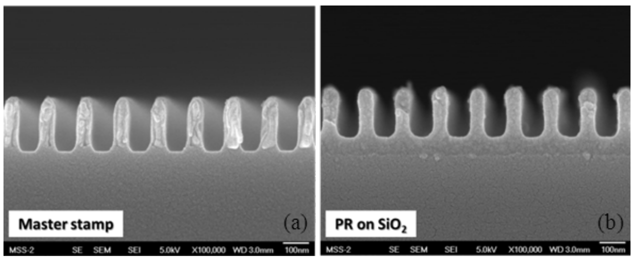

Figure 3: SEM images of (a)master stamp and (b)imprinted resist.

Plasma etching process use ion-reactants produced from specific gas by RF power and possesses physical and chemical characteristics depending on the adoption of etching gases. The etching rates in the vertical and lateral directions are different based on the characteristic of ion-reactant. Ar is chosen to be the ion-reactant and the reaction is physical type which has better aeolotropic property in etching profile because the Ar ion is positive electricity attracted by the cathode in RIE system. For the reasion, the etching rate in direction perpendicularity to the plate of cathode is faster than the horizontal one (Fig. 4). By the well designed process, the etching time was the primary parameter to shrink the linewidth of resist structures.

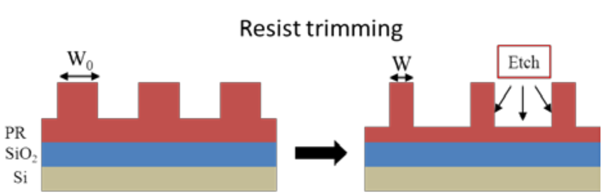

Figure 4: Schematice of resist trimming process.

After the resist trimming process, the metallic etching masks were deposited obliquely onto each side of resist structures by thermal evaporation[8] (Fig. 5). In addition, the final linewidth including metal and resist could be changed by the thickness of metal layer. However, the oblique angle for the first and second deposition were not the same because the geometry of structure would be varied by the first deposition. For this reason, the oblique angle for each deposition were properly designed for achiving symmetrical metallic structures.

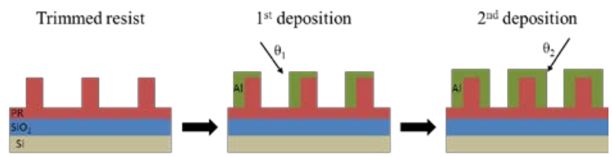

Figure 5: Scheme of double oblique metal deposition technique

By the symmetrical metallic structures, the designed pattern would be transferred to the substrate by reactive ion etching (RIE). Based on material properties, the experimental parameters must be determined such as gas, power, pressure, flow and time (see Table 1). The gas flow and power could directly or indirectly affect the etching rate in the dry plasama etching process. The pressure would determine the mean free path which means the average distance covered by a moving particle between successive impacts or collisions which modify its direction, energy or other particle properties. The process time influences the depth of etched structures in developed process. In this paper, CF_4 and Ar are the main reactive gas for SiO_2 (Fig. 1(f)); Cl_2 and Ar are the primary reactants for silicon (Fig. 1(g)).

		SiO_2	Si
Gas flow	**CF_4**	19	30
	Ar	1	30
Power (W)		100	
Pressure (Pa)		1	
Time (sec)		90	120

Table 1: Experimental recipes for etching silicon dioxide and silicon substrate.

3 RESULTS AND DISCUSSION

3.1 Resist Trimming Process

The linewidths could be fine tuned by adjusting the etching time. The critical dimension could be modified from 55 nm to 37 nm (using 200W RF power with 1 Pa background pressure and Ar 65 sccm flow rate), as shown in Fig. 6 and Fig. 7. The relation between the etching time and linewidths was linear; this phenomenon could provide more procise control for the linewidth. In plasma etching, the imprint residual layer was etched simutaneously. Because of the similar etching rate between the top and bottom, the height of structure could maintain the specific height in different process times.

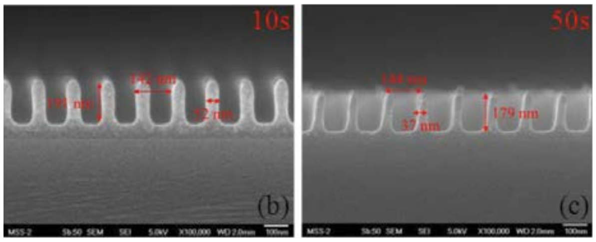

Figure 6: Resist structures with tunable linewidth using the trimming process.

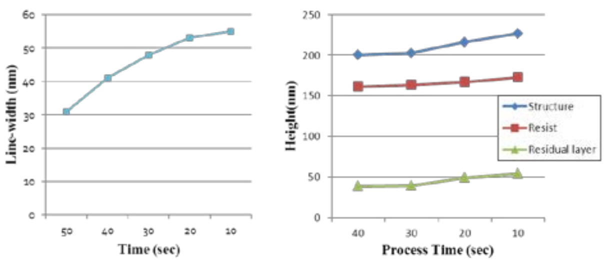

Figure 7: (a)Tunable linewidthes and (b)heights of the resist structures with respect to the trimming time.

3.2 Oblique Angle and Deposition Thickness

Based on the thermal evaporation system, the metal vapor was evapored by heat produced by inputing enough electric current to the resistor and the metallic gas deposits on the one side of structure in a glancing angle. Hence, the designed patterns need to be processed in twice with different incidences. In first deposition, use larger incidence than the angle in second deposition to manufacture the symmetrical structure. However, the incidences are designed depended on the thickness of metal film and the dimensions of patterns. After resist trimming process, the linewidth is changed from 55 nm to 37 nm and the pitch of patterns is 144 nm. Consequently, the depositing angles were 35˚ and 30˚ for depositing 20 nm thick aluminum layer, as shown in Fig. 8. Using double oblique metal deposition can successfully deposit metal molecule on the expected place without common defect such as toppling, cavity or adhesion with the adjacent.

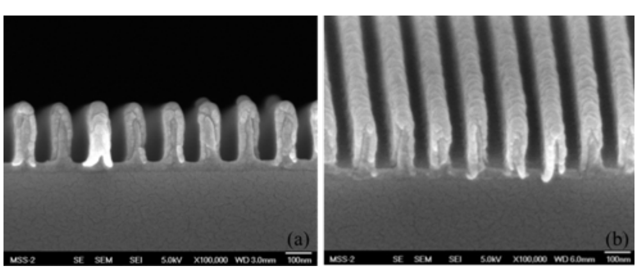

Figure 8: SEM images of aluminnum gratings made by double oblique deposition.

3.3 Silicon Etching using Metallic Etching Mask

For fabrication of working stamp on Si substrates, the original patterns are faithfully manufactured from master stamp by nanoimprint process. Through the relationship between etching time and linewidth, design the expectative dimension in the variation range and fabricated by physical plasma process. When the trimmed resist manufactured, the metallic layer is deposited by double oblique metal deposition as etching msak.

Before the pattern is transferred to the substrate, it is earlier to transfer to resist and silicon dioxide. Use the symmetrical structure including trimmed resist, silicon dioxide and metal film as the hard mask to etch substrates. By this hard mask, not only common substrates but also tough materials could be etched to duplicate the designed patterns for various objectives. Silicon dioxide is compareatively tough than other materials and easily appear etching defect in this layer. By well-developedetching process, the pattern is nearly duplicated to substrates without conspicuous defects in the appropriate experimental parameters. Consequently, use the mixed gas of Cl_2 and Ar to etch Si substrates when PR and silicon dioxide are consummately established (Fig. 9(a)). After etching process finishes, use buffered-oxide-etch solvent to remove the silicon dioxide and the above materials (Fig. 9(b)).

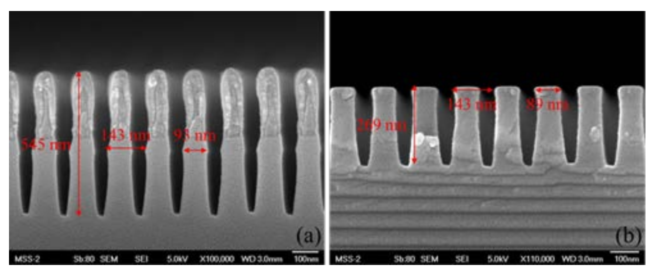

Figure 9: SEM images of (a)etched strucutres and (b)the silicon working stamp.

The deposition angle must be precisely controlled because it is so sensitive that the symmetrical structure with metallic layer would be distorted by the inaccuracy of the deposition angle. Based on the experiment results, the height of structures was the same in different linewidthes without loading effect, which means the etching rate in identical parameters depends on the exposed area. Thus, the oblique angle in specific thickness could be applied to mutative linewidthes of structures.

During the etching process, the etching rate of silicon dioxide was greater than silicon. Because of selectivity and variation of etching rates, the “taper” and “undercut” defect appeared in the silicon dioxide layer and silicon layer; however, using the appropriate etching rates could greatly decrease the defects. For example, use faster etching rate in

SiO_2 to eliminate the "taper" defect; use the slower etching rate in Si to reduce the effect of undercutting. Furthermore, there are other ways to improve etching results. For instance, adding other gas to original mixed gas can change the characteristices of mixed-gas chemstry. Because of the chemical reaction between CF_4 and O_2, it could liberate more fluorine ions than original mixed gas to increase etching rate without raising power. Therefore, it can provide another efficient way to add etching rate without damages like high temperature.

4 CONCLUSIONS

In summary, the study provides the fabrication processes that could produce the working stamp either the identical pattern to the master one or tunable linewidthes, even though the original one is contaminated after a number of imprints because the resist imprinted by the worn stamp can be changed into the symmetrical structures by resist trimming and double metal deposition. Instead of using CVD for depositing metallic etching mask that is usually accompanied with high process temperature, this paper employed PVD process for providing more feasibility of handling polymeric substrates for the applications of flexible electronics.

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