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Fabrication of sub 20-nm wide grooves in a quartz mold by space narrowing dry etching

Kenta Suzuki [a,b,c], Sung-Won Youn [b,c], Qing Wang [b,c], Hiroshi Hiroshima [b,c,*], Yasushiro Nishioka [a]

[a] College of Science and Technology, Nihon University, Funabashi, Chiba 274-8501, Japan
[b] National Institute of Advanced Industrial Science and Technology (AIST), Tsukuba, Ibaraki 305-8564, Japan
[c] JST-CREST, Chiyoda, Tokyo 102-0075, Japan

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ABSTRACT

This paper describes a simple fabrication process of fine groove structures for quartz molds used in UV nanoimprint lithography. Grooves that are finer than the "spaces" in line/space resist patterns can be obtained on a quartz substrate with the aid of thin Cr layer and a dry etching process using CHF_3. The main cause of the groove width narrowing is deposition of fluorocarbon polymer. By changing etching conditions, a large amount of space narrowing is realized. Grooves with widths of 18 nm and 62 nm were successfully obtained from 85-nm and 200-nm wide space resist patterns, respectively.

1. Introduction

The fabrication of sub-100-nm-wide structures is becoming important not only in semiconductor devices but also in nano- and micro-electro-mechanical systems (N-MEMS) such as DNA nano channel and nanophotonic devices [1–3]. Molds used in UV nanoimprint lithography (UV-NIL) for the fabrication of such devices also require fine structures [4,5]. Fabrication of sub-100 nm features requires an expensive electron beam (EB) exposure system operating under optimally-tuned process conditions [6]. In the fine patterning of quartz substrate (e.g. molds for UV nanoimprint), a thin Cr layer is to be deposited prior to resist coating. The Cr layer impedes the charge-up during EB exposure and acts as a hard mask in the subsequent step of quartz etching [7]. The Cr layer is dry etched, typically with a mixture of Cl_2 and O_2 [8], and the quartz substrate is etched with fluorocarbon plasma of CHF_3 and CF_4 [9]. When sub-100 nm wide grooves are fabricated in quartz, both etching processes end up making the groove width wider than required.

Pattern sliming techniques for creating fine patterns below the resolution limit of various exposure systems have been widely studied. A technique has been reported that can easily shrink the line structures of an existing pattern by O_2 ashing [10,11]; and has been applied in the fabrication of sub-100 nm fine gate structures in large-scale integration devices like micro processers and memories. Double patterning is a process combining the bisection of the lithography period and forming the final grating structure with an arbitrary material [12]. To obtain finer groove structures, sidewall spacer transfer patterning technique such as self-aligned double patterning process (SADP) which uses CVD spacer formed adjacent to a core pattern and considered to be applied to flash memory devices is a good method [13,14]. However, it requires complicated deposition and etching steps.

We have fabricated quartz molds for UV-NIL. In the fabrication, structures finer than the patterning size were routinely obtained when the resist patterns on the thin Cr layer/quartz substrate were dry etched using CHF_3 gas [15]. In this paper, we investigated the narrowing phenomenon and the applicability of the phenomenon to fabrication of sub-100 nm groove structures much finer than the patterning size.

2. Experiments

2.1. Cr etching

First, we investigated Cr etching rate. Cr films with a thickness of 10 nm were deposited on Si substrates using a DC magnetron sputtering system at a power of 100 W and Ar flow of 30 sccm. The substrates were dry etched by a reactive ion etching (RIE) system (SAMCO RIE-10NR) using CHF_3 gas. The CHF_3 gas flow rate, chamber pressure, RF power were 30 sccm, 1.3–8 Pa, and 75–225 W. The Cr etching rates were calculated from the etching values for etching time of 5 min measured by an ellipsometer (Gaertner L116S).

* Corresponding author at: National Institute of Advanced Industrial Science and Technology (AIST), Tsukuba, Ibaraki 305-8564, Japan. Tel.: +81 29 861 5512; fax: +81 29 861 7225.
E-mail address: hiroshima-hiroshi@aist.go.jp (H. Hiroshima).

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Table 1
Experimental conditions of space narrowing dry etching.

	Cr etching				Quartz etching			
	CHF_3 flow rate (sccm)	RF power (W)	Chamber pressure (Pa)	Time (min)	CHF_3 flow rate (sccm)	RF power (W)	Chamber pressure (Pa)	Time (min)
Condition A	30	100	1.3	10	30	100	1.3	4
Condition B		150	5					

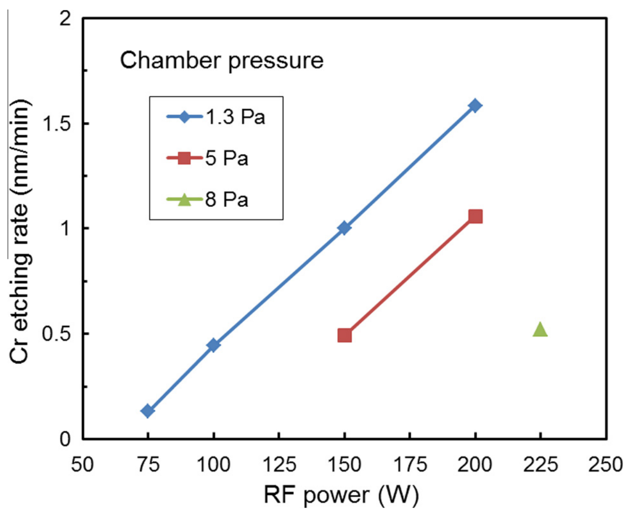

Fig. 1. Dependence of Cr etching rates on RF power under three chamber pressures. CHF_3 gas flow rate is 30 sccm.

2.2. Step-by-step investigation of space narrowing etching process

Next, we fabricated a quartz structure to investigate groove widths after each process step. A quartz substrate of 10 × 10 mm^2 was cleaned by a piranha soak ($H_2SO_4 + H_2O_2$) process. A Cr film with a thickness of 5 nm was deposited on the quartz substrate. A positive-tone EB resist (ZEON ZEP520-A) was spin-coated with a thickness of 300 nm on the substrate. Isolated groove line patterns of 100 nm, and a square pattern of 100 × 100 μm^2 for etched depth measurement were delineated by electron-beam lithography (EBL). The exposure conditions of the EB writer (Elionix ELS-7700) were: an acceleration voltage of 100 kV, exposure beam current of 90 pA, and dose of 280 $\mu C/cm^2$. The exposed patterns were developed in a developer (ZEON ZED-N50) for 1.5 min. The patterns were then etched into the quartz substrate by RIE system using CHF_3 gas. The CHF_3 gas flow rate, chamber pressure, and RF power were kept at 30 sccm, 1.3 Pa, and 100 W, respectively. The typical etching rate of quartz substrate was 25 nm/min. The etching condition also expressed as condition A in Table 1, is the same condition under which we found phenomenon of space narrowing dry etching as mentioned in the introduction. After an etching time of 10 min that corresponded to the right etching time of the Cr film, the patterns were inspected by a field emission scanning electron microscope (FE-SEM; Hitachi S-4800). The EB resist on the substrate was then removed by a resist remover (ZEON ZDMAC) and O_2-RIE, and the patterns were inspected by SEM. By an additional etching for 4 min, the etched depth of quartz became 100 nm, as measured by a contact probe profilometer (Kosaka Lab ET4000M). Finally, the substrate was cleaned by O_2-RIE for 10 min. The fabricated quartz structures were inspected using SEM and the groove widths were determined.

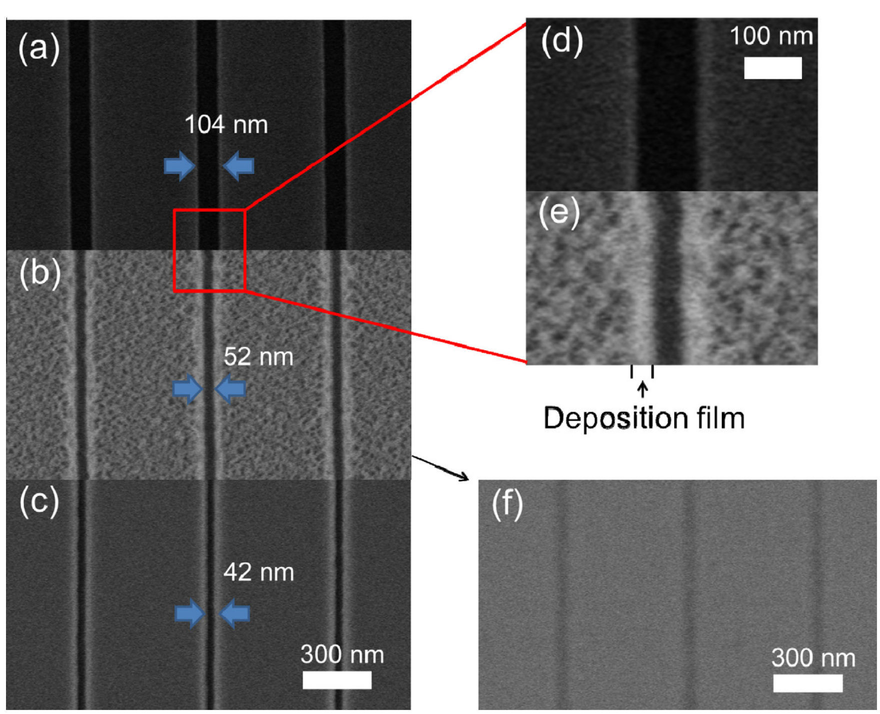

Fig. 2. SEM images of investigated groove widths after each process step: (a) EBL, (b) Cr dry etching, (c) quartz RIE, (d) magnified view of groove of (a), (e) magnified view of groove of (b), and (f) EBL resist removal of (b) by O_2 RIE.