Fast etching of fused-silica gratings with inductively coupled plasma by SF_6

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Fused-silica is an excellent optical material for its high optical quality. Gratings etched in fused silica can be widely used in a variety of optical systems. By lithography and inductively coupled plasma etching technology, fused-silica gratings can be fabricated for mass production with low cost. In order to achieve fast etching rate, gas of SF_6 was used to generate main etching ions. And optimized dry etching conditions were given, including gas flow rate and two radio frequency sources. Experimental results show that the etching rate can reach 1.44 μm/10 min under optimized etching conditions of SF_6 without polymer deposition.

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Keywords: Grating, Inductively coupled plasma, Fused silica, SF_6

1. Introduction

Diffraction gratings are key elements in a variety of optical systems [1], such as a novel strain and position sensor [2], liquid level sensor [3], and so on. By diffraction, gratings can realize numerous properties [4]. Conventional devices may need bulky size or complicated fabrication process. However, elements based on gratings have features of the miniaturization and integration [5-7]. Compared with metal gratings, phase gratings can show high efficiency without insertion loss. Especially, the fused-silica is an excellent optical material with high optical quality which has a wide transmitting spectrum ranging from deep ultraviolet to far infrared. Fused-silica gratings have high damage thresholds and low coefficients of thermal expansion. These properties make them very suitable for high intensity laser systems. They can be fabricated by well developed micro-electronic technique and suitable for mass reproduction at low cost. Fabrication of fused-silica gratings was reported with high efficiency as novel optical elements [8].

Polymer may deposit one the surface during etching of fused silica grating with inductively coupled plasma (ICP) facility, which will reduce the etching rate even stop etching. It is interesting to find ways to achieve high etching rate and depth. Wang et al. optimize etching conditions to fabricate fused-silica gratings with ICP by CHF_3 200 SCCM, Ar 20 SCCM, O_2 5 SCCM, 700 W radio frequency induction source RF_1 and 200 W radio frequency induction source RF_2, under which no polymer deposition can be found. A relatively high etching rate of about 0.5 μm/10 min can be obtained [9]. For deep etching to fabricate novel elements based on fused-silica gratings, it is desirable to improve the etching rate further.

In this paper, we fabricated fused-silica gratings with inductively coupled plasma by SF_6 of 90 SCCM. Etching conditions are optimized to improve etching rate greatly. A series of fused-silica gratings are fabricated at fast etching rate without polymer deposition. An improved etching rate can be achieved with about 1.44 μm/10 min.

2. Experimental set-up

The fabrication process of a deep-etched fused-silica grating includes photolithography and ICP etching. Photolithography is an effective method to form grating patterns, and ICP technology is an important dry etching way to obtain deep-etched fused-silica gratings. Firstly, a photoresist film is spin coated on the chromium layer which is evaporated on the fused-silica substrate. After photolithography exposure and developing, the pattern of grating mask is recorded on the photoresist. By chemical solution, the grating can be transferred into chromium layer to form a mask. Then, the fused-silica substrate with the chromium grating mask is put into the ICP facility for etching. Thus, a deep-etched fused-silica grating is obtained by removing the remaining chromium mask.

In experiments, thicknesses of fused-silica substrate, chromium layer are 1.67 mm, 145 nm, respectively, and coated photoresist film is Shipley, Models1805, USA. Dechromisated solution can be confected with $Ce(NH_4)_2(NO3)_6$ 200 g, 98% CH_3COOH 35 ml, and deioned water 1000 ml.

The ICP facility is applied to fabricate the fused-silica substrate with the chromium grating mask for deep etching. Conventional CHF_3 is the main etching gas to produce most of the ions and erosive neutrals. Since element of F may erode the fused-silica substrate, SF_6 is used for more F element than CHF_3. By experiments, optimized etching conditions are obtained, which are SF_6 90 SCCM, RF_1 600 W to generate high-density plasma, and RF_2 300 W to introduce self-biased electric field.

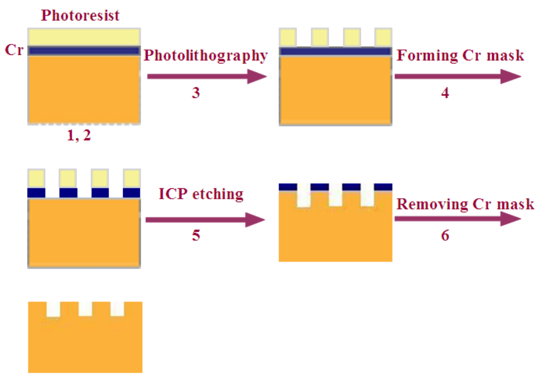
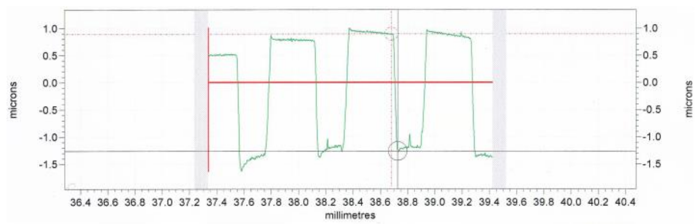


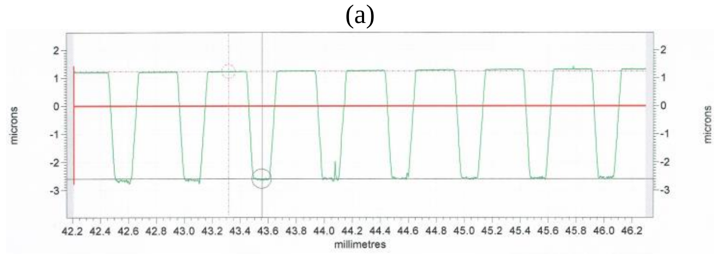
Fig. 1. (Color online) The process flow for fabricating fused - silica gratings with photolithography and inductively coupled plasma technology.

3. Fabrication results

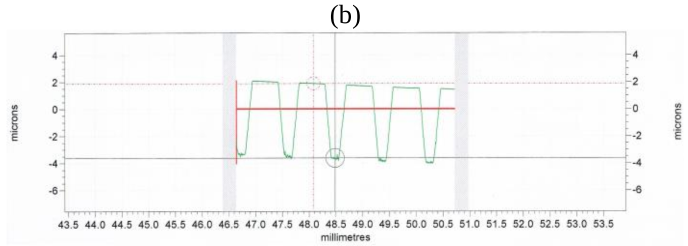
With the optimized etching conditions, fused-silica gratings can be fabricated at high etching rate. Fig. 2 shows a series of etched fused-silica gratings with different etching time for period of 40 μm. Grating depths are 2.16 μm, 3.83 μm, 5.51 μm, 7.02 μm, and 7.56 μm. The etched depth can reach 7.56 μm with good grating profiles. It indicates that deep-etched gratings can be obtained with good quality. Fig. 3 shows the grating depth with different etching time. In Fig. 3, etching rate of 1.44 μm, 1.28 μm, 1.22 μm, 1.17 μm, and 1.01 μm for 10 min can be obtained. One can see that the maximum etching rate 1.44 μm/10 min of SF_6 can be achieved, which is much faster than 0.5 μm/10 min of CHF_3 reported.



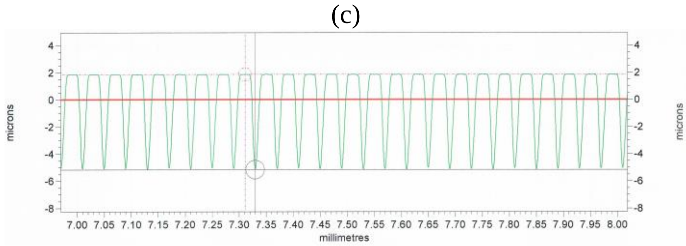
(a)



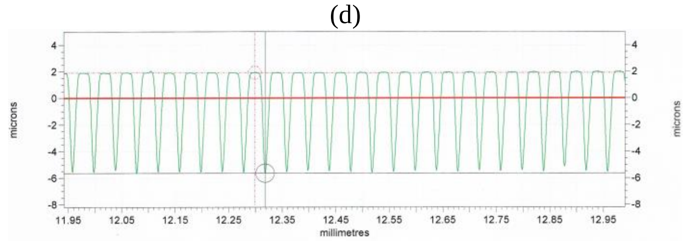
(b)



(c)



(d)



(e)

Fig. 2. (Color online) Profiles of etched fused-silica gratings for the period of 40 mm and duty cycle of 0.5 with Different etching time: (a) 15 min, (b) 30 min, (c) 45 min, (d) 60 min, (e) 75 min.

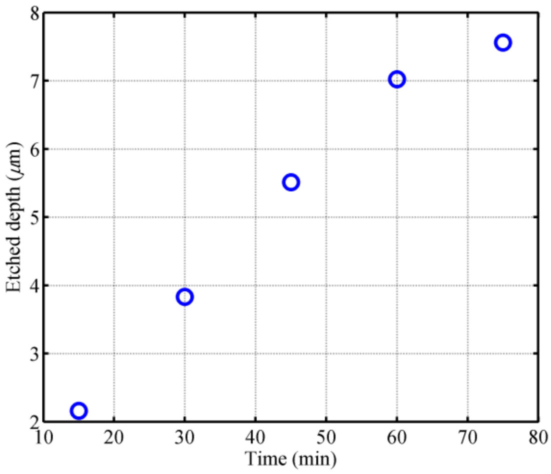


Fig. 3. (Color online) grating depth with different etching time.

4. Conclusion

Deep-etched fused-silica gratings were fabricated with ICP by SF_6. Optimized conditions were presented with SF_6 90 SCCM, RF_1 600 W, and RF_2 300 W. Etched gratings can reach the depth of 7.56 μm. Much faster maximum etching rate of 1.44 μm/10 min than 0.5 μm/10min reported was achieved during fabrication of fused-silica gratings. Fused silica is an ideal optical material with high optical quality. Deep-etched gratings show more novel optical elements. The optimized conditions will facilitate the fabrication of deep-etched fused-silica gratings easily and effectively for high-power lasers.

Acknowledgements

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