Fabrication of integrated lens pair test device

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ABSTRACT

A silica microlens has been proposed which can be integrated with planar optical waveguide circuits. In order to fabricate the microlens, two deep silica etches must be performed. RIE is the prefered process as under certain conditions it is anisotropic. This paper reports on a study of different masking materials and plasma etch conditions trialed for the deep silica etch.

Keywords: Silica, RIE, Microlens, Graded index

1. INTRODUCTION

A silica microlens has been proposed[1] for use in planar optical waveguide circuits. The lens consists of germanium doped silica with a parabolically graded refractive index profile (essentially a slab GRIN lens) to focus light in the vertical direction and a curved front-face to focus light in the horizontal direction.

The integrated waveguide lens pair is illustrated in Fig. 1. The lens pair allows free-space propagation of an optical signal between two opposing waveguides with minimal loss.

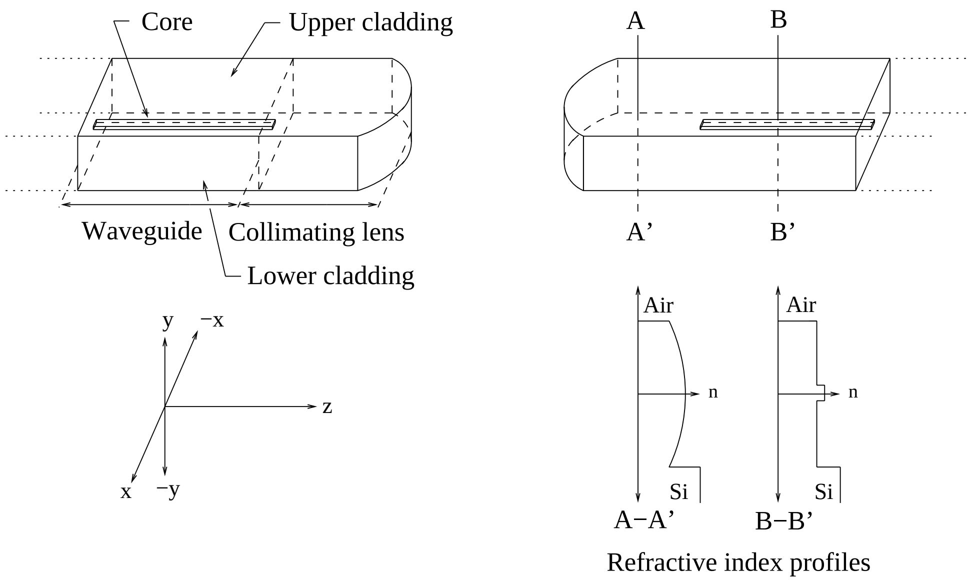

Figure 1. Integrated collimating waveguide lens pair.

In order to fabricate this device, two deep silica etches (of the order of $30\mu m$) are required. This paper reports on a series of etching experiments conducted to determine the most suitable masking material and plasma etch conditions.

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Smart Structures, Devices, and Systems II, edited by Said F. Al-Sarawi,
Proceedings of SPIE Vol. 5649 (SPIE, Bellingham, WA, 2005)
0277-786X/05/$15 · doi: 10.1117/12.582391

2. DEEP SILICA RIE

The etching of the lens convex curvature is by no means a trivial matter. The process has stringent requirements on sidewall verticality and surface roughness, and is of considerable depth.

Reactive ion etching (RIE) is the preferred etching method because under the appropriate conditions it allows an anisotropic profile to be obtained. RIE has been used in the semiconductor industry over the last few decades, however semiconductor fabrication generally only requires etch depths of less than $1\mu m$. Fabrication of the lens pair requires etches to a depth of $30\mu m$ or more.

2.1. RIE of silica — theory

The etching of SiO_2 in a fluorocarbon plasma is an inherently anisotropic process. When unsaturated fluorocarbon species impinge on the oxide surface a thin fluorocarbon layer forms.[2] The physical bombardment of ion species allows this fluorinated skin to adsorb from the horizontal surfaces.

Common plasma chemistries include CF_4 / O_2[2] and CHF_3 / Ar.[3] Both sets of plasma chemistry produce atomic fluorine and CF_x radicals.[2] The O_2 improves the dissociation of atomic fluorine from the CF_4 feed gas.[2] In the CHF_3 / Ar, the presence of the hydrogen encourages a protective polymer layer to form on silicon surfaces, improving selectivity when silicon is used as a masking material. Alternatively, hydrogen can be added directly to a CF_4 / O_2 plasma to achieve the same result.[4]

2.2. Mask selection

Etch masks suitable for oxide etching are typically either photoresist, metal (chromium, nickel or nichrome) or silicon.

Photoresist is typically used for small etch depths ($< 10\ \mu m$) and work particularly well when the etch sample can be cooled (preferably with liquid nitrogen).

Metal masks are suitable for medium to large etch depths ($\approx 20 - 100\mu m$). The metal mask should be resistant to sputtering (ie have a high sputter threshold) and should form non-volatile etch products.

While the selectivity of oxide to metal etch is quite high (typically 30:1 or higher), for a $30\ \mu m$ etch a relatively thick metal layer ($> 1\mu m$) is required. This presents problems in patterning the metal mask. A wet etch is isotropic and so surface roughness of the order of $1\mu m$ can be expected which is too rough for integrated optics applications. A dry etch using chlorine or bromine based gases may alleviate this problem, but was unavailable for this work.

Thick electroplated nickel[5] is one useful alternative for realising deep silica etches however, the selectivity for electroplated materials is not as good as for sputter deposited metals ($\approx$ 20:1) and again the surface roughness may be poor.

Silicon makes an excellent mask material for the deep oxide etch.[4] The addition of H_2 to the fluorocarbon plasma in the RIE allows the formation of polymer on the Si mask surface, enabling a selectivity of $\approx$ 20:1. It is relatively easy to deposit thick layer amorphous silicon layers (through PECVD). Importantly, it is also easy to pattern the silicon layers of this thickness resulting in smooth mask sidewalls.[4]

3. EXPERIMENTAL WORK

The experimental work was carried out using the Hollow-Cathode RIE (HC-RIE) reactor[6] pictured in Fig 2. The hollow cathode configuration increases plasma density when compared to single driven electrode designs. However, the HC-RIE suffers from the same high DC bias problems inherent in designs where all of the RF power is coupled through the electrodes. Inductively coupled plasma (ICP) sources are often used for deep silica etches because a high plasma density can be obtained while independently controling the DC bias. However the ICP source is not always be available due to cost constraints.

The following masking materials were trialled for this work: Sputtered and evaporated Cr, sputtered NiCr, evaporated Al, electroplated Ni and SU-8.

The following process conditions were trialled for this work: $CF_4 + O_2$, $SF_6 + O_2$, $CF_4 + SF_6 + O_2$, and CHF_3 + Ar. Process pressure, RF power and gas concentrations were varied as set out in the table in the results section.

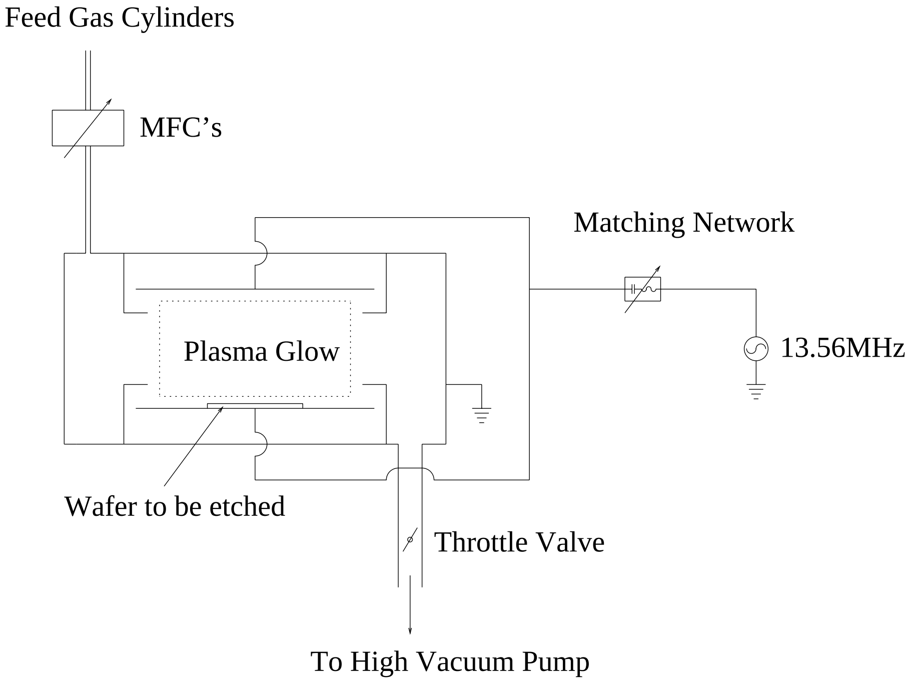

Figure 2. Hollow Cathode RIE chamber.

4. RESULTS

Mask	Power (W)	Pressure (Pa)	CF_4 (sccm)	SF_6 (sccm)	O_2 (sccm)	Selectivity	V_{dc}
Cr	200	30	15		3	35:1	
Cr	200	15		15	3	32:1	-240
Cr	250	25		15	3	35:1	-164
Cr	200	1.5	15		3	30:1	-327
Cr	40	7.5	15		3	28:1	-120
Al	150	30	25		1.5	44:1	
Al	150	10		15	3	30:1	-166
Al	150	1.5	15			10:1	-324
NiCr	150	10		15	3	Etch slowed	-166
NiCr	200	15	10	15	3	100:1	-313
NiCr	125	10	10	10	4	160:1	-186
NiCr	150	30	25		1.5	Etch slowed	
NiCr	200	7.5	15		3	50:1	-370

Table 1. Mask and process conditions.

When CHF_3 + Ar was trialled at 21 Pa, polymer built up on the metal mask. This may be due to the metal surface acting as a catylist, promoting polymer growth. CHF_3 + Ar appears to be useful only for photoresist and amorphous silicon masks.

Electroplated nickel seemed to have a very low sputter threshold and even quite low powers can cause significant grass formation. This is shown in Fig. 3.

Thin SU-8 masks ($\approx 3\mu m$) did not appear to withstand the RIE conditions any better than a standard photoresist (Shipley AZ6130).

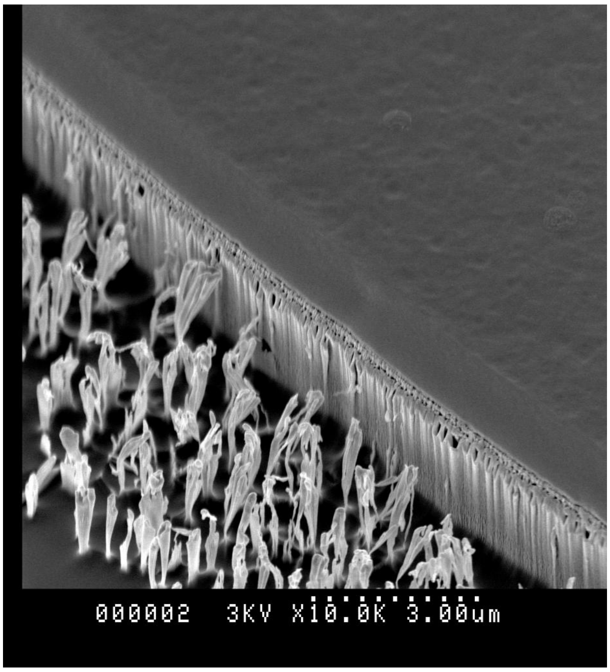

Figure 3. Grass formation caused by redeposition of sputtered nickel mask.

There was no appreciable difference between sputtered and evaporated Cr.

5. DISCUSSION

While the greatest selectivity was achieved using a NiCr mask, the etched silica surface became textured (see Fig. 4), the etch rate reduces and eventually etching ceases. It is assumed that this is due to non-volatile etch products being sputtered and redepositing on the etched surface. This also occurs when Al is used as an etch mask.

It was noted that using SF_6 reduced the DC bias potential which reduces the ion bombardment (and hence sputtering) at the etch surface. For this reason, SF_6 was included in CF_4 / O_2 etches to reduce the bias potential. This tended to improve the selectivity when using NiCr mask material.

The 'cleanest' etch was obtained using the chromium mask, as shown in Fig. 5. As can be seen grass formation is minimal. The authors believe that the chromium is actually slowly etched and does not leave a non-volatile etch product to be resputtered on the etched surface. However, the drawback to using Cr as an etch mask is that the selectivity is limited to about 30:1.

The roughness of the lens curvature has also been investigated. Fig. 6 shows that the surface roughness is of the order of 50nm, which is significantly lower than the operating wavelength (1.55 μm). This roughness is not expected to contribute significant scattering loss to the lens structure.

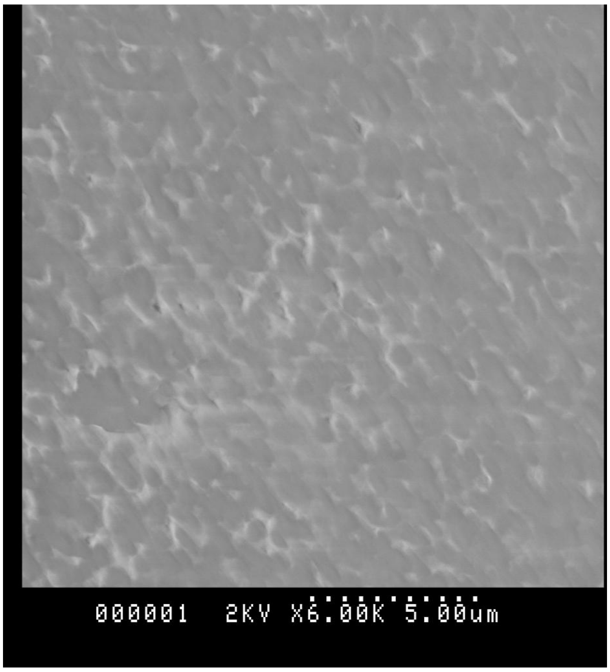

Figure 4. Textured silica surface from resputtered non-volatile etch products.

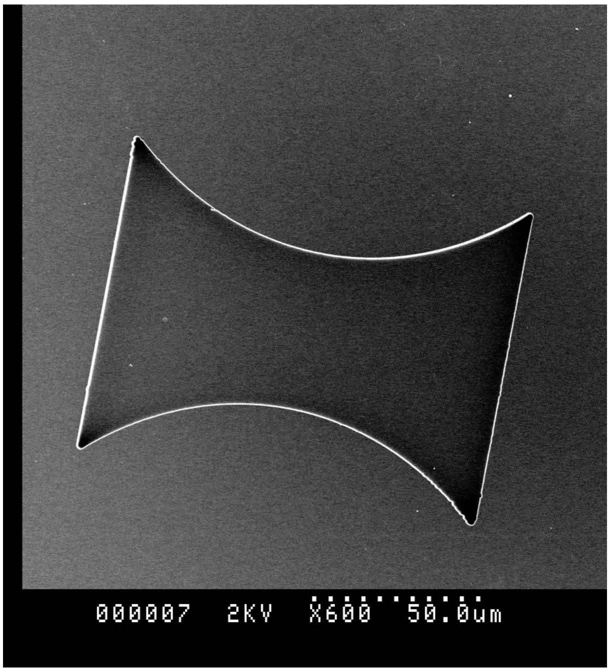

Figure 5. Top view of lens etch. RIE conditions: Cr mask 2000Åthick, CF_4 = 15 sccm, O_2 = 3 sccm, P = 200 W.

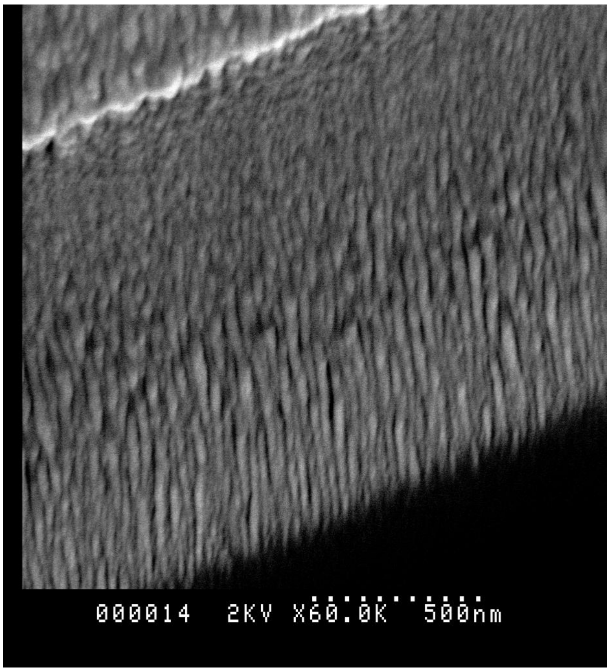

Figure 6. Close-up of lens surface showing surface roughness of the order of $50nm$.

Unfortunately, the selectivity of the oxide etch to chromium is only 30:1. This means that a mask thickness of over $1\mu m$ would be required for a successful etch process. As discussed previously, this thickness of a metal mask is not practical because of the difficulty in patterning a smooth edge in the Cr mask material.

6. CONCLUSION

Further investigation is being carried out using NiCr mask to see if the textured surface problem can be eliminated. Alternatively methods for making a high quality $1\mu m$ Cr mask finish such as dry etching in Cr based gas will also be studied.

7. ACKNOWLEDGEMENT

The authors would like to thank the Australian Research Council for financial support in this research.

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