Deep-UV KrF Lithography for the Fabrication of Bragg Gratings on SOI Rib Waveguides

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Abstract

In this Paper we present a deep ultra-violet lithography (248nm) based double patterning technique for the fabrication of Bragg gratings on SOI rib waveguides. The principle of the used double patterning technique is presented, as well the influence of the process variation on the device performances. The influence of the overlay error was identified as a possibly limiting factor for the application of this technique. Usable structures were realized, in spite of small overlay error and non-rectangular grating profile. The optical characterization showed that the presented technique is capable to provide high performance Si waveguides and Bragg gratings.

Keywords: RET (resolution enhancement technology), KrF lithography, Silicon photonic, Bragg grating

1. INTRODUCTION

Bragg gratings are important waveguide component for achieving wavelength selective filtering. The grating period Λ is given by the Bragg condition $\Lambda=\lambda_0/2n_{eff}$, where λ_0 is the reflected wavelength and n_{eff} the effective index seen by the fundamental waveguide mode. At telecommunication wavelengths of around 1.55µm, Silicon exhibits a refractive index of around 3.5. Hence, a grating period of around 225nm is required. For many applications of very narrow reflection bandwidth and low propagation loss for the transmitted wavelengths are essential. This can be achieved only by keeping the grating depth very small, in the order tens of nanometers. A shallow grating implies an increase of the overall grating length, up to the millimeter range [1]. Here we apply 248nm optical lithography for the fabrication of the waveguides Bragg gratings because of its potential for low cost fabrication of photonic structures. To achieve the required half pitch of smaller than 130nm by using binary mask is challenger and requires resolution enhancement technologies. Half-pitch double exposure lithography (DEL) or double patterning lithography (DPL) techniques as resolution enhancement technologies are widely known and in use in modern lithography for microelectronics fabrication to achieve smaller pitches [2]. In this work, we apply double patterning based on previous experience gained with this technique [3, 4]. The principle of the DPL technique is shown in Figure 1.

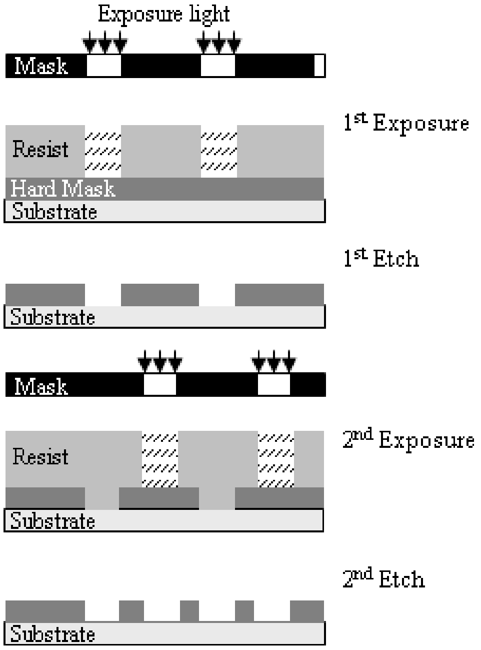

Fig. 1: Process flow for the double pattern technique.

2. EXPERIMENT

1.4µm SOI rib waveguides on 1µm buried oxide were used. The dimensions of the waveguides were optimized for low intrinsic loss to allow the implementation of waveguide Bragg gratings with a length in the order of centimeters.

A scanning electron microscope (SEM) image of a rib waveguide is shown in Figure 2. Typical rib parameters are 1.7µm rib width and 0.5µm rib depth, which assures single mode operation of both polarizations.

To realize Bragg grating structures on these waveguides, the grating spaces were fabricated first using the DPL /3, 4/. The antireflective hard mask of 21 nm LPCVD Si_xN_y /5/ with optical constants of n = 2.6 and k = 0.68 have been adjusted for the DPL application. The lithography was carried out with a KrF Scanner (Nikon S207D, NA = 0.82, σ = 0.4) and chemical amplified positive resists UV2000 (DOW) with a thickness of 325 nm. The OVL was measured and corrected by using KLA 5200. The process window optimization were carried out by PRODATA software using KLA-Tencor's SEM eCD2 for the CD measurements.

For the etched Bragg grating a simple one-step process using CF_4/Ar chemistry was used. Uniform hard mask opening and a subsequent etching into underlying silicon to realize 50nm deep grating lines was performed. In view of future integration aspects the final etch process for waveguide definition was based on a well proven dry etch recipe used for shallow trench etching in IHP 0.13µm SiGe BiCMOS technology. The multi-step process starts with etching of antireflective coating layer, followed by hard mask opening of a stack consisting of different oxide and nitride layers. The Si waveguide ribs were formed by chlorine-based plasma etch step (500nm depth). In both dry etch steps a poly Si decoupled plasma source (DPS) etch chamber (Applied Materials) was used.

3. RESULTS AND DISCUSSION

An image of a waveguide with Bragg grating is shown in Figure 3. The profile is not perfectly rectangular, a small overlay error, and some surface roughness at the bottom of the spaces is visible.

One major problem of DPL concerns the overlay accuracy of pattern level 1 and level 2. For this technique the Bragg grating CD is determined by wafer alignment of 15nm (mean +3s) for the Nikon S207D /4/. Due to the overlay error the original Bragg grating is split in to two sub-gratings with different duty cycles (ratio between spaces and lines). Therefore the overlay error should impact the efficiency of the grating. To obtain a first, semi-quantitative impression of the effect of the overlay error, we have performed rigorous coupled wave analysis (RCWA, [6-9]). The result shows (Figure 4) that the overlay error impacts strongly the grating efficiency, with a pronounced polarization dependence of the effect. Low efficiency and polarization dependence are undesirable for most applications. Minimization of overlay error is therefore mandatory for the application of DPL in Bragg grating fabrication. A first estimate of the required overlay accuracy is ≈10nm. Other errors are related to variations of the profiles of the spaces between etch 1 and etch 2 (i.e. control of critical dimensions, CD).

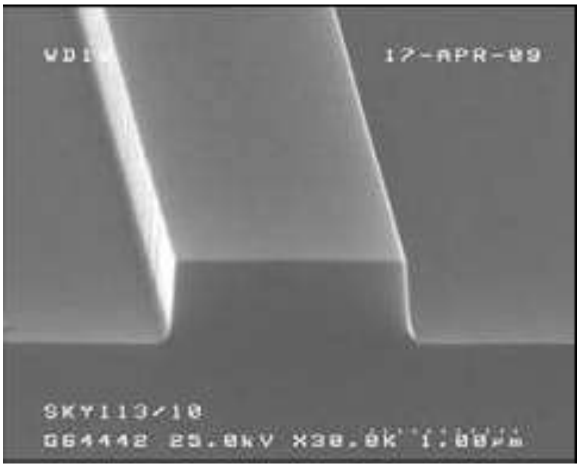

Fig.2: Scanning electron micrograph of SOI rib waveguide without Bragg grating.

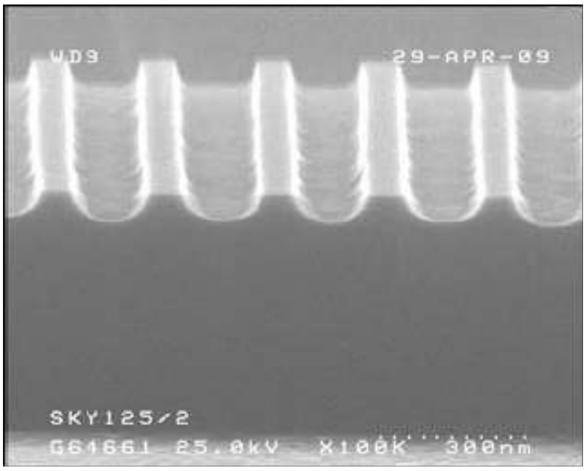

Fig. 3: Sideview perspective of the grating pattern on the waveguide rib.

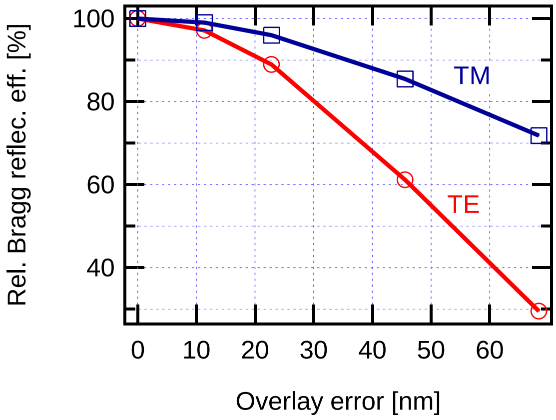

Fig. 4: Dependence of the Bragg grating efficiency (reflection) on overlay error (shift between mask level 1 and 2). Here, a grating period of 228nm was assumed.

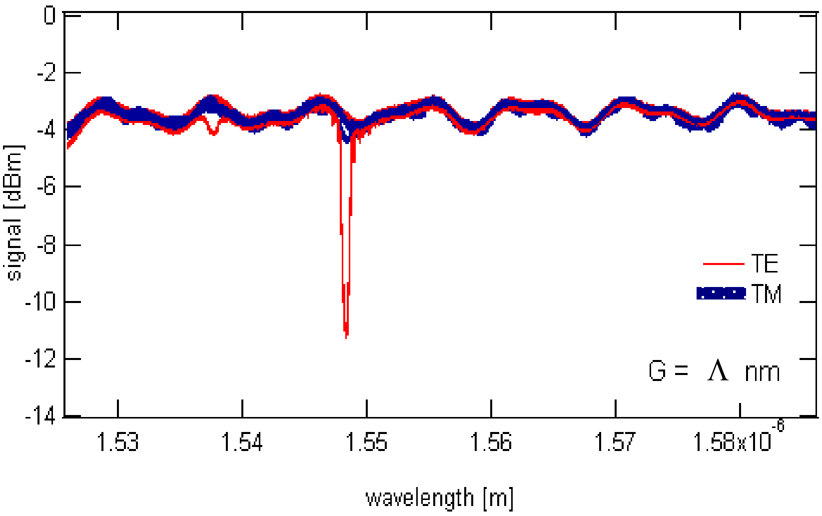

Fig. 5: Transmission spectra of DUV lithography patterned Bragg grating on SOI rib waveguides for TE- and TM – polarized light. The grating has a pitch of 226nm, is 50nm deep etched, and exhibit an overall length of 800µm.

An optical characterization of the fabricated devices was performed, to study the quality of the grating performance. The characterization consisted of a transmission measurement, where a single pass transmission through the silicon waveguide was measured. A good in- and out-coupling efficiency was achieved using lensed fibers, which also avoided any direct contact between waveguide facets and fiber. The analysis of the spectral behavior of the gratings was performed with a tunable laser source between 1500nm and 1600nm. A polarization controller allowed setting the polarization of the propagating light. The grating transmission was calculated as the ratio between the power transmitted by a waveguide with grating, and the one measured from a waveguide without grating.

Fig. 5 shows the measured transmission curves for a Bragg grating. The curve exhibits a strong dip for TE-polarization around $\lambda = 1.55\mu m$ over a bandwidth of 0.7nm. At other wavelengths the loss introduced from the gratings is around 0.3dB.

4. CONCLUSION

DUV lithography (248nm) and double patterning technique for the fabrication of Bragg gratings on SOI rib waveguides were studied experimentally. The influence of the overlay error was identified as a possibly limiting factor for the application of this technique. Usable structures were realized, in spite of small overlay error and non-rectangular grating profile. The optical characterization showed that the presented technique is capable to provide high performance Si waveguides and Bragg gratings.

5. ACKNOWLEDGEMENTS

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