

Distributed Bragg reflectors on InP platform fabricated with deep-UV technology

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We present the realization of first-order Bragg gratings in indium-phosphide (InP), realized for the first time with 193 nm ArF deep-ultraviolet (DUV) lithography. This technology was developed to be compatible with the COBRA generic InP integration process. The parameter space of the distributed Bragg reflectors (DBRs) was explored with numerical calculations. The fabricated DBRs were characterized and the results are compared to the simulation. The impact of manufacturing errors is discussed.

1. Introduction

The Distributed Bragg Reflector (DBR) is an important waveguide component for achieving wavelength selective filter functions. It has been widely used in multi-wavelength and tunable laser sources in the last years [1,2]. It is our goal to extend the COBRA platform [3] with DBRs to enable new functionalities of the photonic integrated circuits (PICs) that can be realized in the platform. To enable the DBR as a standard building block, the main challenge is the development of the high precision lithography technology. In Bragg gratings, the period is given by the Bragg condition:

$$\Lambda = \frac{\lambda_B}{2n_{\text{eff}}} \quad (1)$$

where λ_B is the Bragg wavelength and n_{eff} is the effective refractive index of grating material [4]. For the InP platform operating at wavelengths around 1550 nm, this requires a grating period of about 240 nm, which is below the resolution limit of most conventional lithography techniques. So far, e-beam lithography and holographic lithography have been used to achieve the state-of-the-art performance [5,6]. However, e-beam lithography has the drawbacks of limited writing area and being time consuming, and holographic lithography is limited to patterning grating features over a large area of the wafer, which limits the design freedom.

A leading-edge 193 nm deep-ultraviolet (DUV) scanner combines high throughput and high flexibility, enabling the integration of DBRs and more complex grating based reflectors and filters [7,8]. DUV has a limited Depth of Focus (DOF) which reduces the process window for small feature sizes. This technology poses new requirements on the flatness of the InP wafers, similar to commonly used specifications for Si.

In this work, we have successfully used the 193 nm DUV scanner (ASML PAS5500/1100B) to fabricate DBRs on InP wafers, for the first time. The InP wafers with a total thickness variation (TTV) of around 1 μm have been obtained by using a double-sided polishing process. The layer stack of DBRs for DUV fabrication was designed by numerical calculations. The fabricated DBRs were characterized and compared to the simulations. The influence of the process errors on the device performance was analyzed.

2. Parameter design for fabrication

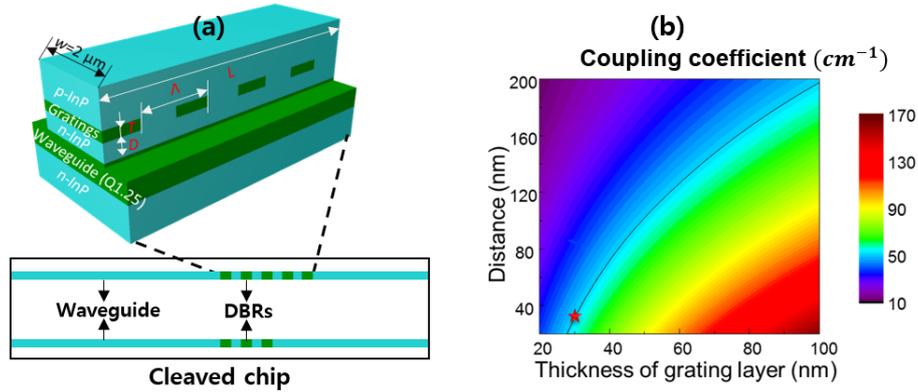


Figure 1: (a) Schematic picture of the designed DBR; (b) Contour plot of the calculated coupling coefficient as a function of the thickness T of the grating layer and the distance D between the waveguide layer and the grating layer.

Figure 1(a) shows the schematic picture of a cleaved chip with integrated DBRs on waveguides and a 3D view of the designed DBR. We use an n-doped InP substrate, a 500-nm-thick Q1.25 waveguide layer, an n-doped InP layer in between the waveguide layer and the grating layer and a p-doped top cladding with a thickness of 1.5 μm .

The coupling coefficient κ of the designed DBR is determined by the thickness T of the grating layer and the distance D between the waveguide layer and the grating layer. Figure 1(b) is a contour plot of the calculated coupling coefficient as a function of T and D . It indicates that the increased confinement factor of the propagation light in the grating layer, which is caused by an increased thickness T or a decreased distance D , results in a higher coupling coefficient. The coupling coefficient that we are aiming for is 50 cm^{-1} , shown as the black line. We used a T of 30 nm and a D of 32 nm in our fabrication, shown as the red spot. The period determines the Bragg wavelength of gratings, according to eq. (1). The peak reflectivity of gratings depends on the product of κL , according to eq. (2) [4]. At the Bragg wavelength, the reflection of a DBR grating is given by:

$$R = -\tanh(\kappa L) \quad (2)$$

where L is the length of the DBR.

3. Fabrication of Bragg gratings

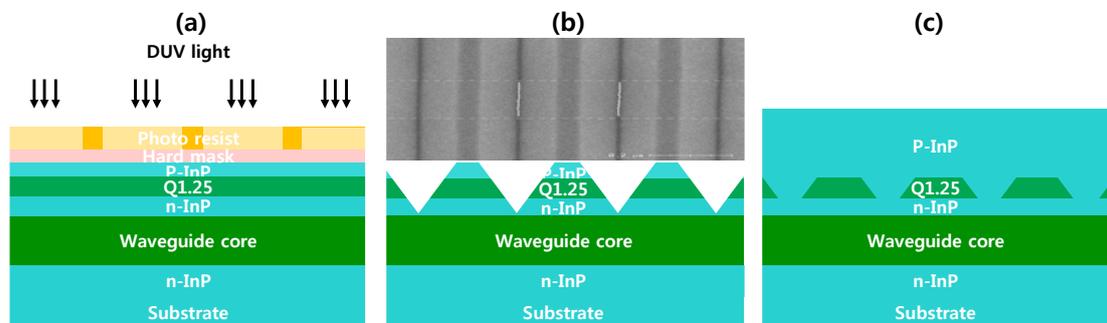


Figure 2: Process flow of Bragg gratings with DUV scanner and wet etch.

Figure 2 shows the process flow of Bragg gratings with DUV scanner and wet etch. By using the DUV technology, the pattern is firstly transferred from the reticle to the photo

resist, then from the photo resist to the hard mask. Then a wet etch is used to etch the materials along the crystal planes. So the sidewalls are angled as shown in the schematic and in the SEM image in Figure 2(b). After regrowth of an InP layer, we obtain the DBR as shown in Figure 2(c). The duty cycle is approximately 0.5, which is determined by several factors, including the layer thicknesses of the grating and spacer layers, the duty cycle of gratings in the hard mask and the crystal plane.

4. Measurements and discussions

A set of DBRs with periods of 236.3, 237.8, 238.5, 239.9 and 240.1 nm and lengths of 200, 400, 500, and 600 μm are characterized. To enable a fast and self-referenced analysis, the gratings are placed in individual straight waveguides that form a Fabry-Pérot cavity. Figure 3(a) shows the measured reflected power of samples with a fixed DBR length of 400 μm and different periods. It shows the Bragg wavelength shifts relative to the reference Fabry-Pérot fringes due to the variation of the grating period. The Bragg wavelength of 8 different samples at each period on the same wafer has been characterized, their mean values are shown as blue spots in Figure 3(b). The standard deviations are smaller than 0.7 nm, which is sufficient to target the wavelength for tunable DBR gratings. The Bragg wavelength increases linearly as the period increases, which indicates a reproducible lithography process over a large wavelength span.

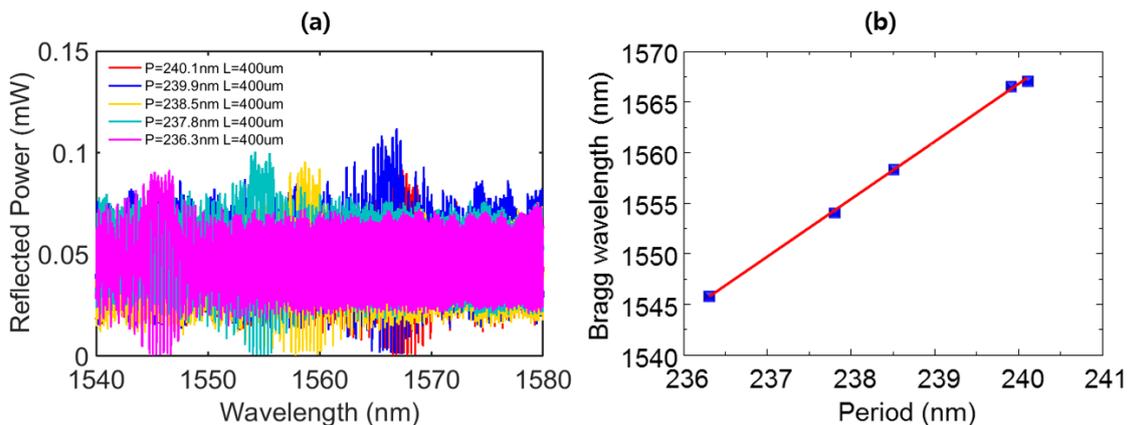


Figure 3: (a) Measured reflected power of samples with a fixed DBR length of 400 μm and different periods. (b) Measured Bragg wavelength (blue spots) as a function of period and a linear fit (red line) of the measured data.

Figure 4(a) shows the measured reflected power of samples with a fixed DBR period of 240.1 nm and different lengths. The reflected power of samples cannot represent the reflection of DBRs due to the losses induced by coupling, waveguide propagation and Fabry-Pérot interference. Figure 4(b) shows the extracted reflection spectra of the DBRs. The advantage of using a cleaved chip is that the measurement is self-referenced. The coupling and propagation losses can be normalized with the average loss outside the peak. The Fabry-Pérot cavity has been filtered by taking the moving average of the reflected power with a window that was sufficiently small to not increase the width of the reflection peak. The results show that the same period results in the same Bragg wavelength and the longer length of gratings results in higher peak reflectivity. However, the peak reflectivity of the DBRs is lower than the simulated values. This can be due to deviations from the target widths, layer thicknesses or propagation losses and can be verified with a structural

analysis of the fabricated samples. First the chips will be anti-reflection coated for direct measurements to be compared with those presented here.

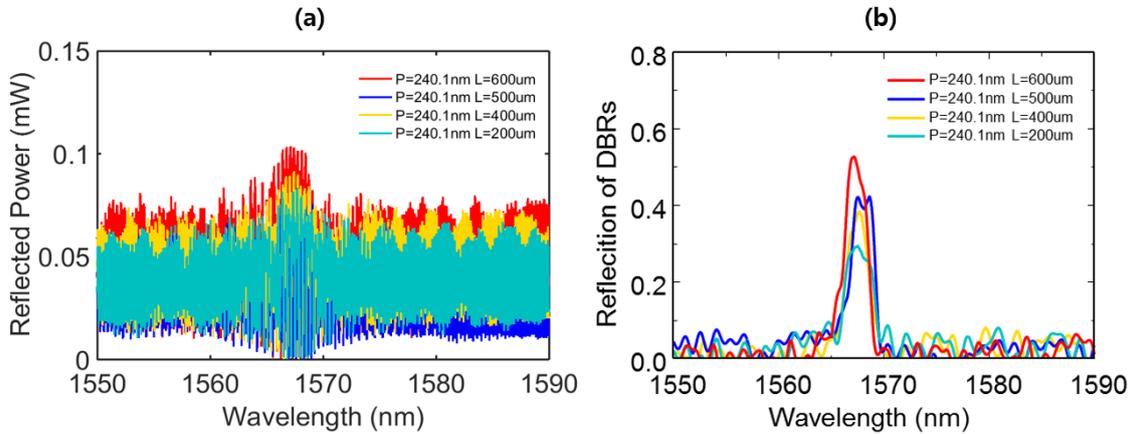


Figure 4: (a) Measured reflected power of samples with a fixed DBR period of 240.1 nm and different length. (b) Extracted reflection spectra of the DBRs.

5. Conclusion and acknowledgement

We have realized DBR gratings in InP-based materials with 193 nm DUV technology for the first time. Their fabrication is compatible with the COBRA generic integration platform. The reflection properties of DBRs with different periods and lengths have been characterized. The Bragg wavelength of the DBRs can be precisely controlled, which is needed for laser applications. The effect of fabrication errors of layer thicknesses, waveguide width and duty cycle will be further studied.

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6. References

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