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APODIZED BRAGG FILTERS ON InP-MATERIALS RIDGE WAVEGUIDES USING SAMPLED GRATINGS

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ABSTRACT: *This paper presents the first investigation of a novel method to obtain an apodization effect on common InP ridge waveguide filters. It consists of the use of particular sampled gratings. Such apodized filters measured transmission spectra present an enhanced rejection of about 20 dB of the adjacent sidelobes, which experimentally validate the concept.* Microwave Opt Technol Lett 48: 1627–1630, 2006; Published online in Wiley InterScience (www.interscience.wiley.com). DOI 10.1002/mop.21682

Key words: *apodized filters; ridge waveguides; semi-conductor materials*

1. INTRODUCTION

Photonic filters can be considered as key devices for various system applications. The well-known example is optical transmission systems using wavelength multiplexing. But a lot of other applications can be found, for example, in microwave photonic systems. Realizing filters on semiconductor material can enable us to get some integrated functions. In any case, a sharp definition of the optical bandwidth is required. In order to separate and select efficiently the only desired wavelength range, we need the most selective filter possible. A common semiconductor filter with a uniform coupling coefficient which consists, in our field of inter-

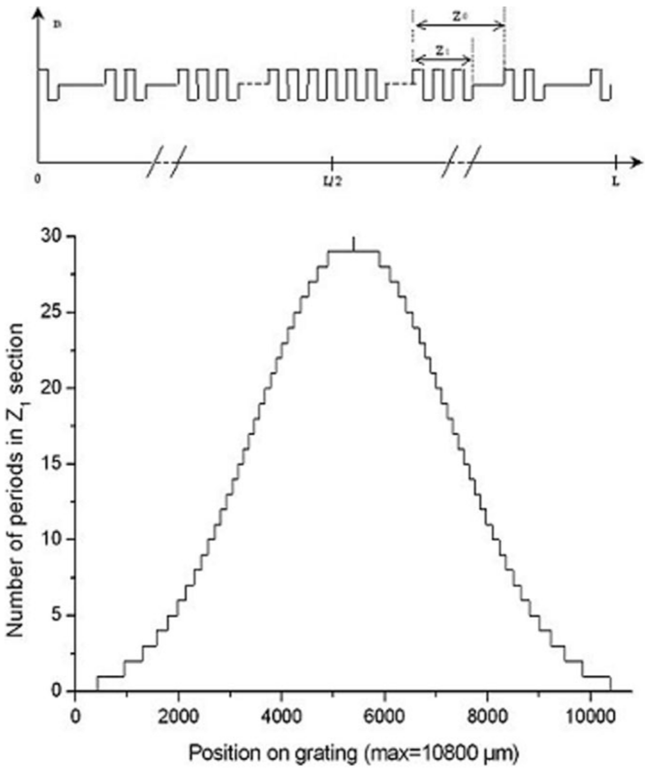

Figure 1 Sampled grating design: schematic view (top) and Gaussian distribution of Z_1 sections

est, in a waveguide integrating a uniform Bragg grating, exhibits a poor rejection of the adjacent channels wavelengths. The significant suppression of the so-called side lobes by more than 20 dB can only be achieved using an apodization technique. This method, which is commonly used for optical fibers, consists of a modulation of the coupling coefficient along the grating, which increases the rejection outside the band, that is, of the adjacent channels, in the case of WDM transmission [1, 2]. This coupling coefficient modulation is then realised using index-contrast variation, which can be easily obtained in optical fiber. The use of this method is almost inapplicable in the case of semiconductor-based optical integrated circuits, since it is rather difficult to obtain a modulation of the refractive index. As gratings are etched into the semiconductor material, one way to modulate the intensity of the grating strength along the structure is to modulate the grating depth; this technique involves several difficult and critical processing steps and is almost practically not achievable. Another approach is to vary the duty cycle of the grating along the structure [3], which also leads to huge lithography control. The purpose of this paper is to propose a new method to realize an apodized semiconductor filter that does not need severe lithography control, except obviously that of the grating pitch. This technique consists in using a sampled Bragg gratings for which apodization is only linked to mask layout.

2. APODIZED FILTER DESIGN

A sampled grating is a grating that periodically alternates sections with and without grating encryption [4]. In this case, and for the main order of reflection, the coupling coefficient for such a grating is given by the following relation (1)

$$\kappa(0) = \kappa_0 \frac{Z_1}{Z_0}, \qquad (1)$$

where Z_1 is the length of the grating section, Z_0 is the sampling length (Z_1/Z_0 can be so called as the filling factor of the sampled grating), and κ_0 is the coupling coefficient of a grating section. As the modulation of the refractive index contrast is realised by apodization in a periodic structure and as the coupling coefficient is directly linked to this refractive index contrast, we can expect to reach an apodized grating by modulating the coupling coefficient. This effect can be obtained by using a sampled grating, which allows the variation of the filling factor all along the structure and then the variation of the coupling coefficient $\kappa(0)$. The most common modulating function used for apodization is the Gaussian function. We chose then to vary the filling factor and so the length Z_1 as a Gaussian function of z, while keeping the sampling length Z_0 constant (Fig. 1). We obtain then the relation:

$$Z_1(z) = Z_0 \exp\left[-A \cdot \left(\frac{z - L/2}{L}\right)^2\right], \qquad (2)$$

where L is the total length of the filter, and A is a parameter which defines the width of the Gaussian function. The corresponding coupling coefficient of the sampled structure, and then the refractive index contrast, is now a Gaussian function of z.

In order to validate this concept, we chose to realize such a structure. The applied Gaussian index modulation has a coefficient A of 16, which leads to a narrow Gaussian shape. The length Z_0, which is the sampling length and defined as a constant, is fixed to 7.2 μm. This value allows us to have, as a maximum, 30 periods of a 240-nm pitch grating. The total length L of the apodized filter is 10.8 mm. The number of periods in each grating section follows then the function (2) and is represented in Figure 1.

3. DEVICE FABRICATION

The epitaxial structure was made by gas source molecular beam epitaxy on InP substrate. It consists of a 1-μm InP top cladding layer and a 0.36-μm InGaAsP (cutoff wavelength $\lambda_{gap} = 1.15$ μm) core layer, which are grown on the substrate. Uniform filters with overall length of 5 and 10.8 mm, as well as 10.8-mm-long apodized filter (following sampled grating design given in Fig. 1) have been fabricated simultaneously. The grating pitch is always 240 nm. A 50-nm-thick Si_3N_4 layer is deposited on the top InP layer by plasma enhanced chemical vapour deposition. The grating patterns were first defined by electron beam lithography (EBPG 5000+ from Leica) on a 70-nm-thick positive electron-beam resist

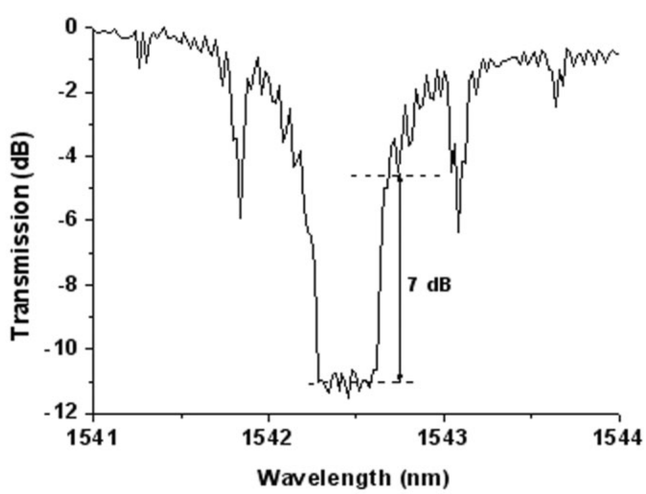

Figure 2 Measured transmission spectrum for 5-mm-long uniform filter

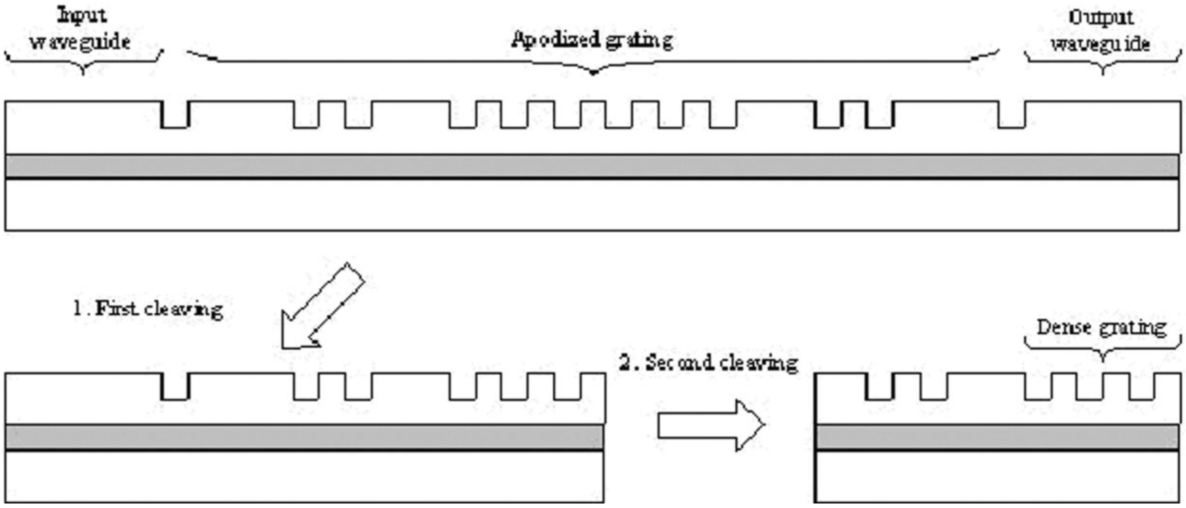

Figure 3 Schemes of the entire and cleaved apodization filters tested

(PMMA 3%/495°K) deposited on the Si_3N_4 layer. It is developed using a solution of MIBK and isopropanol (IPA). The grating pattern is then transferred to the Si_3N_4 layer by using CF_4/CHF_3 reaction ion etching (RIE). Using this silicon nitride mask, gratings are etched into the top InP cladding layer down to 0.5-μm depth with a $CH_4/H_2/Ar$ RIE (Plasmalab 80 from Oxford Instruments). Ridges then have to be formed. The already-made gratings are protected by a 2-μm-thick negative tone optical resist (NLof) layer. The 3-μm-wide ridge patterns are formed by a UV insolation into this layer. It is developed using MIF 326 developer. Using this resist mask, the ridges are realised by etching the top InP cladding layer down to 0.7-μm depth with the same $CH_4/H_2/Ar$ RIE process (except a longer etching time) that was used for the etching of the gratings.

3. EXPERIMENTAL SETUP

The filters are deposited on a two-stage/two axis mount system and excited using an end-firing technique. A conical-shaped lensed fiber, mounted on a three-stage piezo-controlled micro-positionner, is used to launch the light into the device and a cleaved fiber, mounted on a similar positionner too, is used to collect the device output light. The illuminating source is a 1520–1570-nm tunable

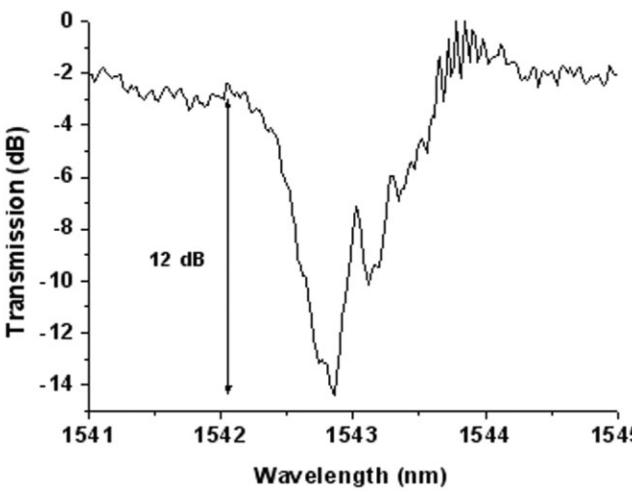

Figure 4 Transmission spectrum for the half-apodized filter

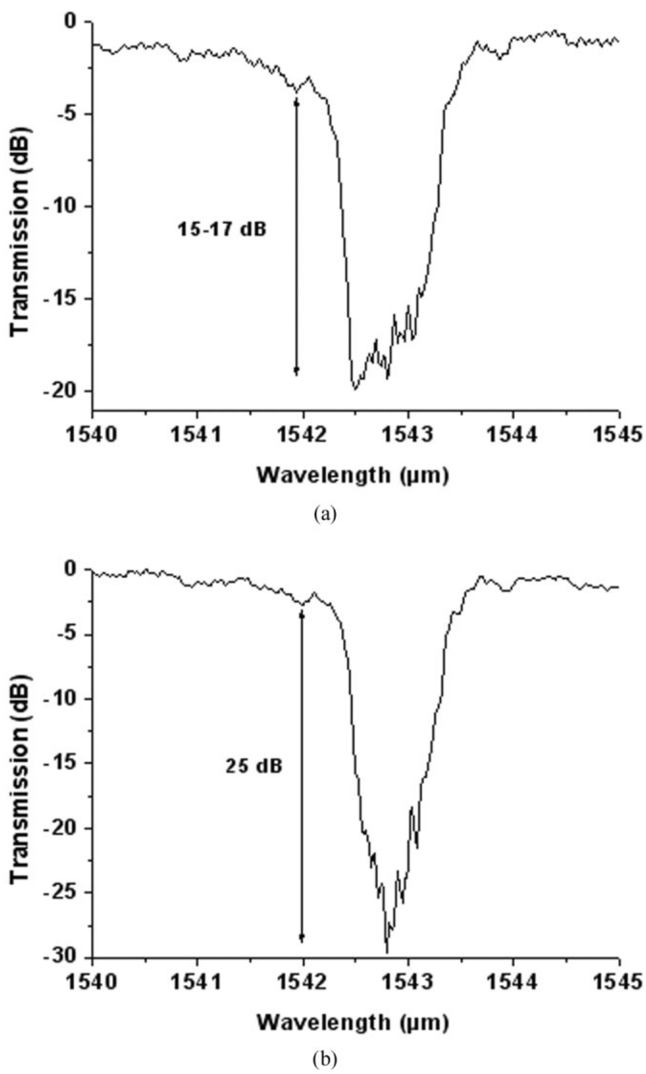

Figure 5 Measured transmission spectra of apodized Bragg grating filter (half), with light injection from the dense grating side (b) and the other side (a)

laser (EXFO FLS2600). The transmitted optical power is measured with a powermeter (HP 81532A), working in the 800–1700-nm range. Both the optical source and detector are connected to a computer by GPIB links. By varying the wavelength of the tunable source laser and measuring the transmitted power, we can plot the transmission response of the various gratings.

4. RESULTS AND DISCUSSIONS

As a first experiment, we measured the transmission spectra of uniform Bragg grating filters. For the two different lengths of 5 and 10.8 nm that were fabricated, the measured spectra demonstrate a square bandwidth, for both lengths, of 0.6 nm, centered at 1542.44 nm, with rather prominent sidelobes (Fig. 2). The rejection between the main dip and the first sidelobes is measured to be in the 7–10-dB range. Strong sidelobes of 0.6-nm spacing are also present in a periodic way. These Fabry–Perot resonances likely may result from systematic stitching errors which occur during the EBL writing of gratings [2, 5]. However, they do not represent an obstacle with the validation of the apodization effect.

As a second experiment, we tested the apodized structures as previously defined, which integrates 100-μm-long straight input and output waveguides before the grating in order to insure a good coupling of the light into the device (Fig. 3). Surprisingly, we could not detect any transmitted light for this device. Then, as a third experiment, we cleaved the apodized device in two symmetric parts, at the middle of the filter, for which the total length is now about 5.4 mm (Fig. 3). When the light is injected into the remaining straight input waveguide, no light could be detected at the output, exactly as for the second experiment. When the light is injected into the dense grating side, we could now observe a transmission. The transmission spectrum can then be measured and is given in Figure 4. Compared with the one obtained for a uniform filter of comparable length presented in Figure 2, we can notice that the base at 0 dB of the spectrum is smoother. We obtain a clear apodization effect of the transmission spectrum with a rejection of 12 dB. As a fourth experiment, we cleaved away the remaining straight input waveguide of the previous device (Fig. 3). By injecting successively from one side then the other one, we could observe a transmitted mode at each output and so two transmission spectra, which are presented in Figures 5(a) and 5(b). They both present an excellent suppression of sidelobes, better than 20 dB, outside a bandwidth of almost 1 nm, whereas a uniform grating with the same dimension has only a 7-dB suppression outside the almost same bandwidth. The last two experiments show with evidence that all measured transmission spectra present a clear apodization effect which is very high, for example, a secondary dip no longer exists.

5. CONCLUSION

We have demonstrated experimentally a promising new technique to apodize semiconductor Bragg filters by means of a Gaussian law sampled surfacic grating, provided that the input waveguide with low-density grating is removed from the devices. More than 20-dB sidelobe suppression is then achieved.

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