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Wavelength Sensitive PIN Photodetector Using Guided Mode Resonance

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1. Introduction

This abstract presents a new structure of resonance cavity enhanced (RCE) PIN photodetector (PD)[1], which consists of a bottom distributed Bragg reflector (DBR), a cavity with InGaAs multiple quantum wells (MQWs) for light absorption and a top mirror using guided mode resonance (GMR). The resonant wavelength of conventional RCE-PD with two DBRs is usually fixed after the sample growth because the cavity length is not adjustable. However, in our RCE-PDs with the well-designed GMR reflector can select the definite absorption wavelength during device processing. By changing the filling factor of the grating for GMR, effective cavity length can be assigned. Therefore, we can fabricate an array of RCE-PDs on a single chip, on which every PD aims for a specific wavelength by means of GMR grating design.

In the following sections, we will report a concise description of the objectives of the study, the method of approach, the significant theoretical and experimental results and a brief conclusion.

2. Design Theory

GMR is a coupling effect between the grating diffraction and the guided mode[2, 3] as the grating is taken as an effective uniform waveguide. That is, as light is diffracted by a grating, it propagates in various directions. When one of diffracted rays couples into the guided mode of grating, a resonant condition can be achieved which is the so-called GMR effect. The significant point is that it can bring nearly 100% reflectivity over a wide range of wavelengths[4]. This phenomenon in planar dielectric gratings can be numerically calculated with the rigorous coupled-wave analysis (RCWA)[5].

To make broad-band GMR reflectors at about 1 μm, we use a strong refractive-index-modulation grating consisting of GaAs (n = 3.54) and air (n = 1) and select the low diffraction order and guided-mode order[6-9]. For TE and TM modes being the same, we design a square lattice grating with circular holes (Fig. 2) with various filling factors defined as below,

$$1-\pi\frac{r^2}{\Lambda^2} \qquad (1)$$

,where r is the radius of hole, and Λ is the period of grating.

The n-typed bottom DBR on n^+-GaAs substrate is composed of 14.5 periods λ/4 GaAs/AlAs layers. A graded superlattice is inserted at GaAs and AlAs interface to reduce the series resistance caused by the band discontinuity. The graded DBR exhibits a reflectivity more than 95% from 925 nm to 980 nm.

Cavity length is the key component in our devices because it determines absorption wavelength. Unlike conventional RCE-PDs whose cavity length is, the optical distance between top and bottom DBRs, our resonant wavelength is determined by the GMR reflector and the bottom DBR (Fig. 1). The basic concept comes from the simple fact that, by changing the filling factor of GMR reflector, its effective refractive index of waveguide is also changed. Fig. 1 shows the electric field distribution in the device, the field in grating resembles the zero order field distribution in homogeneous planar waveguide. Therefore, effective refractive index of the grating increases as the filling factor of the grating increases, and then the field distribution would be more confined in the grating. As a result, the longer wavelength field would sustain in the cavity according to the boundary condition of EM wave. By using simulation tool, we can design the absorption wavelength over the desired range by adjusting the filling factors. A largest span of 60 nm is possible as we know from the simulation. Note that the change of the fill factors will not alter the reflectivity of GMR as it is a broad band reflector.

The InGaAs MQWs are placed at the anti-nodes of electric field to maximize the absorption efficiency. Since these components couple to each other, we have to put them together to perform the simulation by means of a commercial software, DiffractMOD3.1, produced by RSoft Design Group.

3. Fabrication

First, the sample structures are grown by a solid-source MBE system then an e-beam lithography is used to define the grating pattern on PMMA. The pattern is then transferred into the PECVD SiNx layer which served as the hard mask to finish the grating on GaAs by dry etch. Next, the mesa and ohmic contacts were made by standard wet etch and e-gun metalization, respectively. Finally, we use diluted HF (1:25) to remove AlGaAs sacrificial layer to form a suspended GMR grating.

4. Experimental results

We first measure the responsivity spectrum of the device by using a commercial Fourier transformer for infrared (FTIR). Fig. 2 shows the measured results of the RCE-PDs with four filling factors. The hump below 875 nm comes from GaAs absorption. A clear peak near 950 nm is observed, which is the resonant absorption of InGaAs MQWs. As we can see that the resonant peak shifts from 946 nm to 954 nm when the filling factor is increased from 0.615 to 0.678. The peak responsivity around 950 nm is about 0.16 A/W corresponding to an external quantum efficiency of 21 %.

By assuming the absorption coefficient of 0.1 μm^{-1} for the InGaAs QW, we compare the experimental data with the simulation results in Fig. 3. The measured peak wavelengths are consistent with the calculated ones but it is not for the band width. The experimental full-width-half-maximum (FWHM) is considerably larger than the simulated one, which may be because of the nonuniformity of the GMR mirror processing and the unintended absorption from the detection area without the grating.

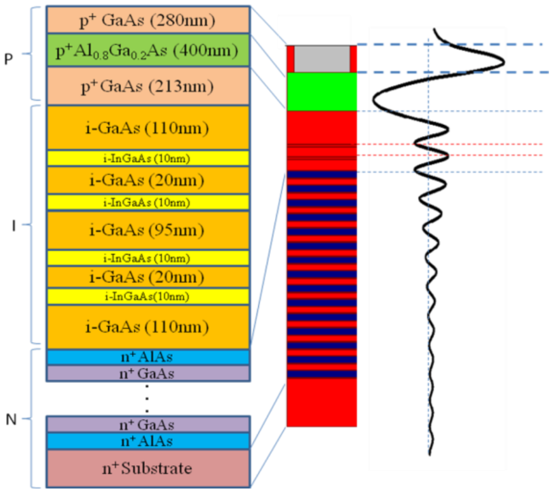

Fig. 1 Detailed device structure (left) and the calculated electric field distribution (right).

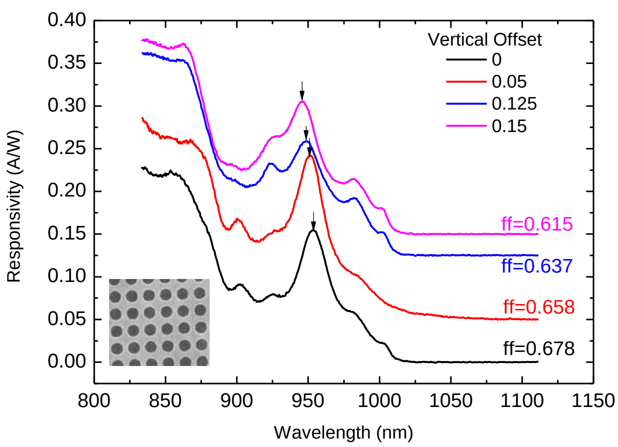

Fig. 2 The measured responsivity spectrum of four device with different fill factor. The inset shows the SEM picture of the GMR grating.

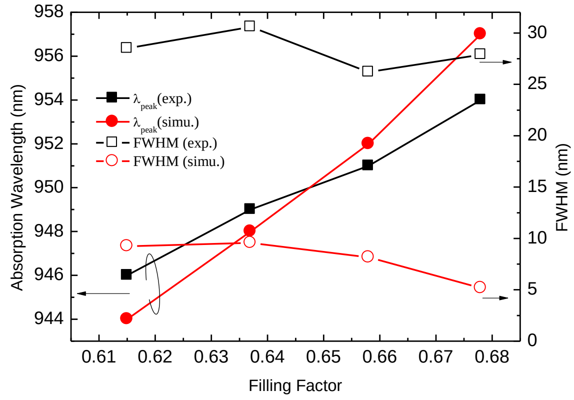

Fig. 3 Experimental and theoretical absorption peak wavelengths and FWHMs v.s. the filling factors.

5. Conclusion

We presented the theoretical and experimental results of a novel RCE-PDs using GMR effect as the top mirror. The resonant wavelength can be selected simply by adjusting the fill factor of the GMR grating mirror. Our work pave the way to realize the wavelength sensitive PDs array on a single chip, which may be of great potential in various applications such as optical interconnect and miniature spectrometer.

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