Mode-Guided Infrared Absorption in Ge/SiO_2 Grating for Large-Angle and Broadband Photodetection

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***Abstract*—The numerical simulation of the electromagnetic properties of the Ge/SiO_2 grating structure with bottom distributed Bragg reflector. With mode guiding in Ge, the structure exhibits an absorption angle of 100° and broadband behavior from 1300 to 1500 nm.**

***Keywords*—grating, mode guiding, Ge, broadband**

I. Introduction

Autonomous driving is a fast-growing field. Multiple sensors are essential for self-driving functions. The light detection and ranging (lidar) system [1] is one of the critical sensors used to construct three-dimensional real-time environment. To avoid human-eye damage and anti-glare by the laser beam, the best wavelength for lidar is 1550 nm, thus requiring infrared detection. The reflected light from the detected object is Lambertian, and the object may be located obliquely forward. It is thus necessary that the detection device have a large detection angle. In addition to the large angle, a photodetector in lidar application needs high responsivity and high response speed to ensure effective and fast recognition of the object [2]. Many designs are suggested to fulfill absorption and speed requirements, such as guided-mode resonance [3] and Fabry-Perot resonance [4]. However, those designs have limited applications for large-angle, broadband lidar because they have either a small detection angle or a small wavelength range of high responsivity.

This work utilizes the Ge/SiO_2 integrated grating with distributed Bragg reflector (DBR) on Si substrate to design a novel surface illuminated absorber for infrared photodiodes that have a high absorbance and a large absorption angle in a broadband from 1300 to 1550 nm.

II. Electromagnetic Simulation

The finite element method (FEM) (COMSOL Multiphysics 6.0) was used to perform the optical simulation. The simulation is based on the Helmholtz equation to solve steady-state electric field distribution. Figure. 1 illustrates the structures used in the simulation. There are two periods of the distributed Bragg reflector (DBR) employing Si and SiO_2 on top of the Si substrate. The thickness of each layer was designed as quarter-wavelength. Because of the large difference in the refractive indices of Si (n = 3.48) and SiO_2 (n = 1.45) at the 1550 nm wavelength, the reflectance of this DBR is estimated to exceed 90%. A modified absorbing grating was designed on top of the DBR. The grating has a thickness of 1 μm and a period of 2.8 μm. The width of the Ge and SiO_2 regions in a period are 2 and 0.8 μm, respectively. Two structures, A and B, were used in the simulation. Their difference is that the top layer in the DBR (underneath grating) is Si in structure A and is Ge in structure B. This simulation calculates TE-polarized plane infrared light at 1550 nm incident to the structure from the air at various angles. The top and the bottom boundaries of the simulation frame are perfect-matching layers that absorb the transmit wave without reflection. The lateral is a periodic boundary to simulate an infinite grating structure.

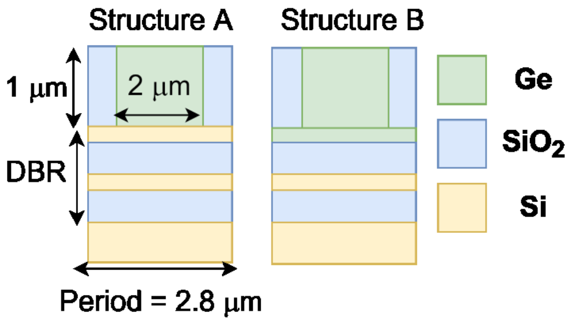

Fig. 1. Structures used in the numerical simulation.

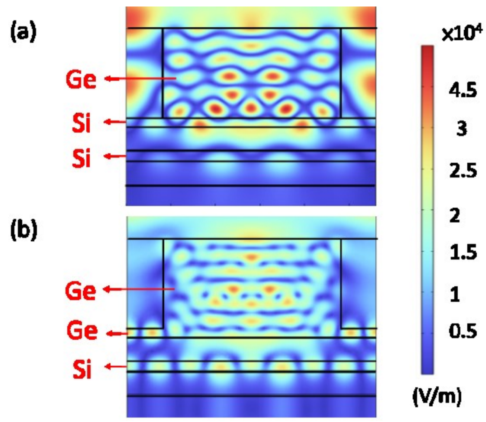

Fig. 2. Spatial distributions of the electric field amplitude in (a) structure A and (b) structure B at normal incidence at 1550 nm.

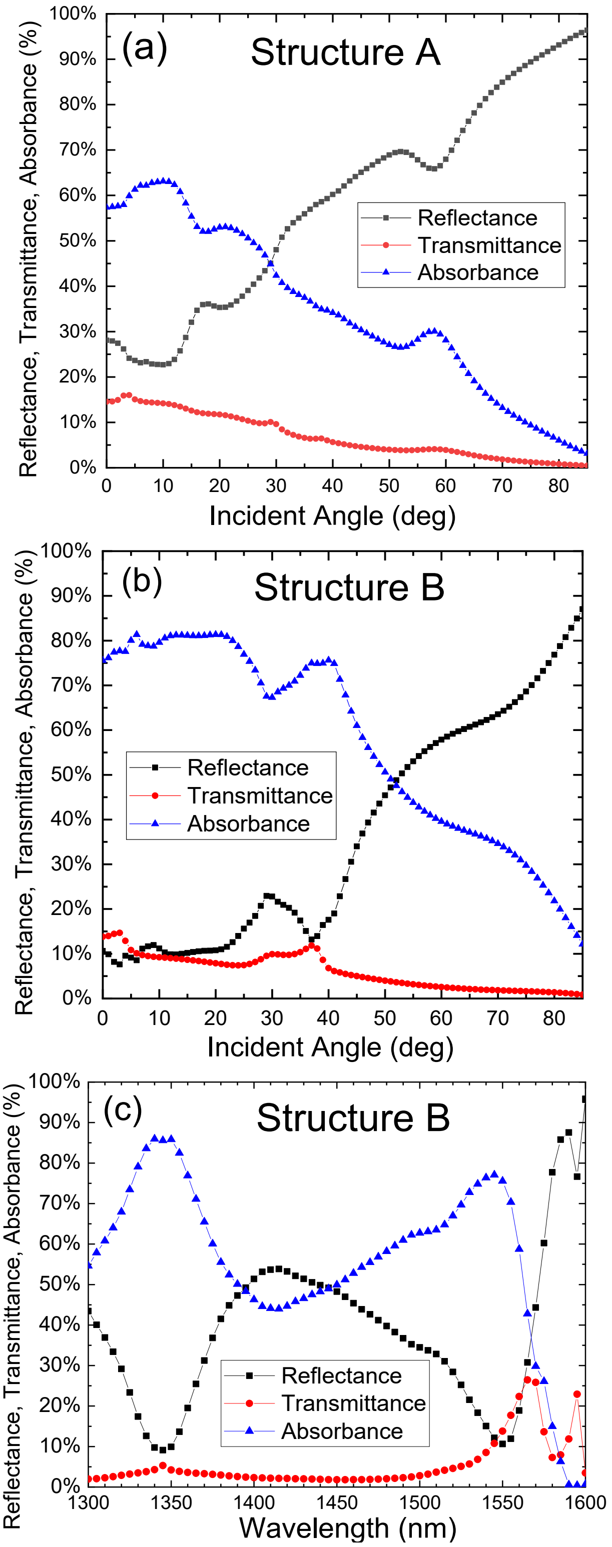

Fig. 3. Reflectance, transmittance, and absorbance of (a) structure A and (b) structure B at 1550 nm wavelength as functions of the incident angle. Reflectance, transmittance, and absorbance of (c) structure B at normal incidence as functions of the light wavelength.

Figure 2(a) shows the spatial distribution of electric field amplitude in structure A at 1550 nm for normal illumination. A strong electric field amplitude was found in the Ge region in the grating. This is the nature of electromagnetic waves because Ge has a higher refractive index than SiO_2. The light in the SiO_2 is coupled into the Ge region. Therefore, some lateral modes are found near the bottom of the Ge/SiO_2 grating. However, a significant amplitude is still found in the SiO_2 pillar, primarily because of multiple reflections from the surrounding interfaces. Since the bottom of the grating is a Si/SiO_2 DBR, a vertical resonance is found from the amplitude distribution near the air/Ge interface. By contrast, amplitude distribution exhibits a different pattern when the top Si layer in the DBR is replaced by a Ge layer to change structure A to structure B. Because Ge has a higher refractive index (n = 4.25) than Si (n = 3.48) at 1550 nm, the bottom reflectance is enhanced, causing the vertical resonance in the Ge region to be enhanced. This is found in the amplitude distribution shown in Fig. 2(b). In addition to the vertical resonance, the amplitude distribution at the Ge/SiO_2 interfaces in Fig. 2(b) differs from that Fig. 2(a). The electrical field is repelled out of the SiO_2 layer, forming a vortex-like mode path that guides the electrical field into the Ge layer underneath the SiO_2 pillar. This guidance avoids the electrical field remaining in the non-absorbing SiO_2 layer and enhances the Ge "waveguide" absorption.

Figure 3(a) shows the reflectance, transmittance and absorbance of structure A as functions of the incident angle at 1550 nm wavelength. The low transmittance is the result of the DBR reflector. The maximum absorbance of structure A exceeds 60% at incident angles in the range of 5 to 10°. The largest incident angle for an absorbance exceeding 50 % is 25°. Figure 3(b) shows the transmittance, reflectance, and absorbance of structure B as functions of the incident angle at 1550 nm wavelength. Structure B shows an extensive enhancement in absorbance characteristics over structure A. The maximum absorbance of structure B exceeds 80% at incident angles between 5 and 25°. The absorbance exceeds 50 % for all incident angles between 0 and 50°, thus a large detection angle of 100°. Figure 3(c) further shows the transmittance, reflectance, and absorbance of structure B at normal incidence as functions of the light wavelength. The absorbance of structure B exhibits a broadband behavior over the range from 1300 to 1550 nm, covering a primary optical communication range.

In summary, the mode-guided grating structure offers wide-angle and broadband photodetection suitable for light detection and ranging application and appropriate for fiber communication.

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