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Wavelength Selective Plasmonic Grating for CO_2 Gas Sensing Based on Nondispersive Infrared

Shuga Yahagi[1], Shinya Kumagai[1], Katsuya Masuno[2], Makoto Ishii[2], and Minoru Sasaki[1]

[1] Toyota Technological Institute,
2-12-1, Hisakata, Tenpaku-ku, Naogya 468-8511, Japan
Phone: +81-52-809-1840, E-mail: mnr-sasaki@toyota-ti.ac.jp
[2] Yazaki Corporation
1500 Mishuku, Susono, Shizuoka, Japan

Abstract

The Au grating is realized for confining the blackbody radiation except the wavelength absorbed by CO_2 gas, which relates many bio-applications. With the design having the tolerance against the shape error, the effect of 3D layout having the azimuth is taken in account. The obtained emission agrees well with the CO_2 absorption band.

1. Introduction

Nondispersive infrared (NDIR) is the well-established gas sensor. This physical method is good for sensing CO_2, since it has low chemical activity. CO_2 monitoring relates many bio-applications. The animals and plants generate CO_2 with respiration and being influenced by the environmental CO_2 gas. CO_2 concentration is measured from the attenuation at the absorption band of 4.2-4.3μm wavelength. Main IR emitter is still blackbody having the broad band, and it is inefficient since the almost wavelength is not used for sensing. The wavelength selectively is required.

The surface plasmon polariton (SPP) cannot couple with the propagation light, but can combine with the grating in a narrow condition. The plasmonic grating realizes the wavelength selectivity. We had proposed the indirect wavelength selective IR emitter, but the emission wavelength deviated from the CO_2 absorption band[1]. In this study, the grating for the accurate emission wavelength control is fabricated.

2. Indirect IR emitter proposed

Figure 1 shows the principle of the IR emitter proposed. The microheater is on Au grating. Its blackbody radiation is reflected back at the upper reflector and the lower Au grating. As an exception, the photon with the wavelength close to the grating pitch and with the specific incident angle excites SPP. SPP propagates on Au grating and then releases light from the output opening. The grating decides the spectrum.

3. Grating designs and SPP excitation

Au grating is investigated using rigorous coupled-wave analysis. The grating with a rectangular shape has almost same SPP excitation even when the top or the bottom corners are rounded. The important parameters are found as the grating pitch, the duty ratio, and the depth. The smaller duty ratio makes the peak wavelength longer and their distribution wider. The deeper grating makes the peak wavelength longer and narrowing the peak group.

Figure 2 shows the grating design based on 2D model. SPP excitation peaks cover the wavelength 4.2-4.3μm with

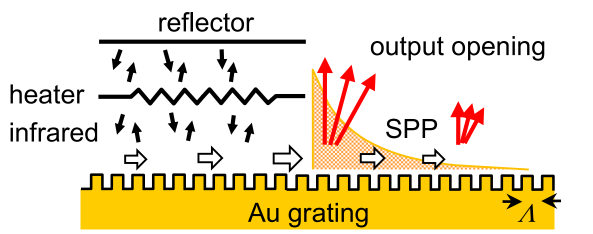

Fig. 1: Schematic drawing for showing the principle of the wavelength selective emission propagated through SPP.

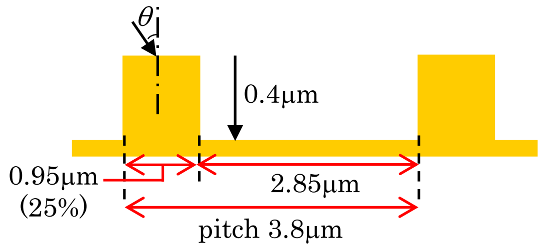

Fig. 2: Grating design based on 2D model.

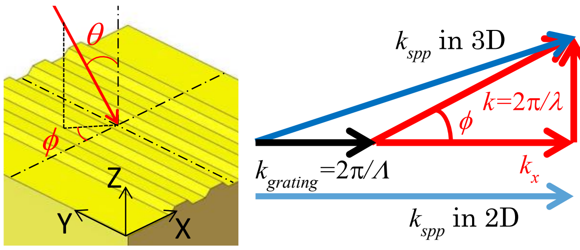

Fig. 3: Grating in 3D layout and related vector relation showing the conservation of the momentum.

the margin. This design allows the size error up to ±0.1μm, in the duty ratio and the depth, which can change in the fabrication. Figure 3 shows the 3D grating model. The conservation of the momentum between SPP and the incident photon with the grating (in x-axis) select the wavelength. In 2D model, k_{spp} and k_x are balanced with the incident polar angle θ. In 3D, k_y is mixed together as shown in the inset of the vector. The balanced k_{spp} becomes larger in 3D. This means that the coupled wavelength becomes shorter.

Figure 4(a) shows the grating design based on 3D model. Figures 4(b) and 4(c) show the SPP related peaks when azimuth ϕ is 0° and 30°, respectively. The peak group shifts to the shorter wavelength. Since the actual layout will have the azimuth in the larger percentage, the decided design takes importance to that having the longer pitch (4.2μm).

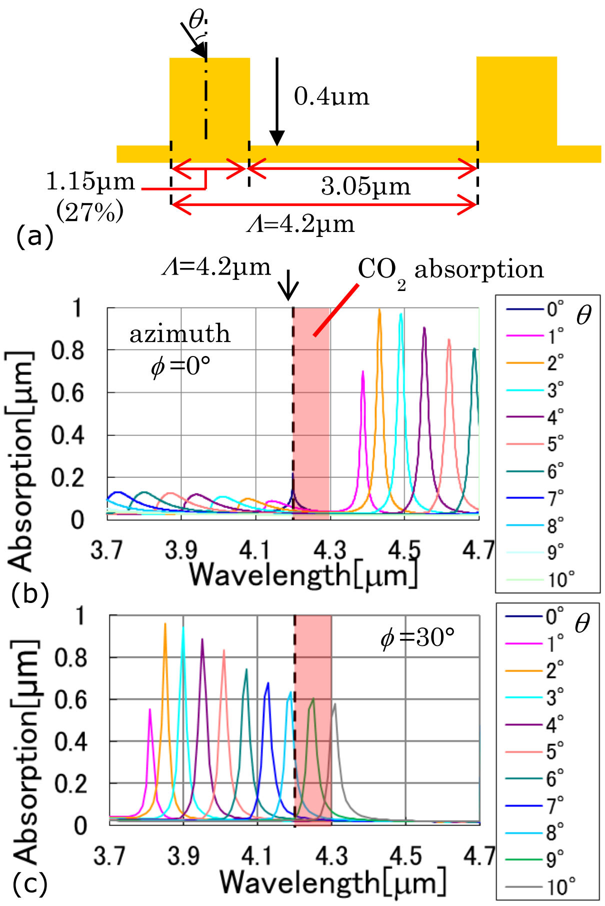

Fig. 4: (a) Grating design based on 3D model. (b)Simulated SPP related peaks when azimuth ϕ is (b) 0° and (c) 30°. The legend shows the polar angle.

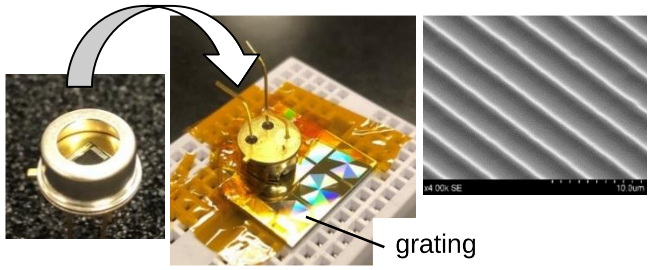

Fig. 5: Setup for observing the wavelength selectivity using the blackbody emitter on the fabricated grating.

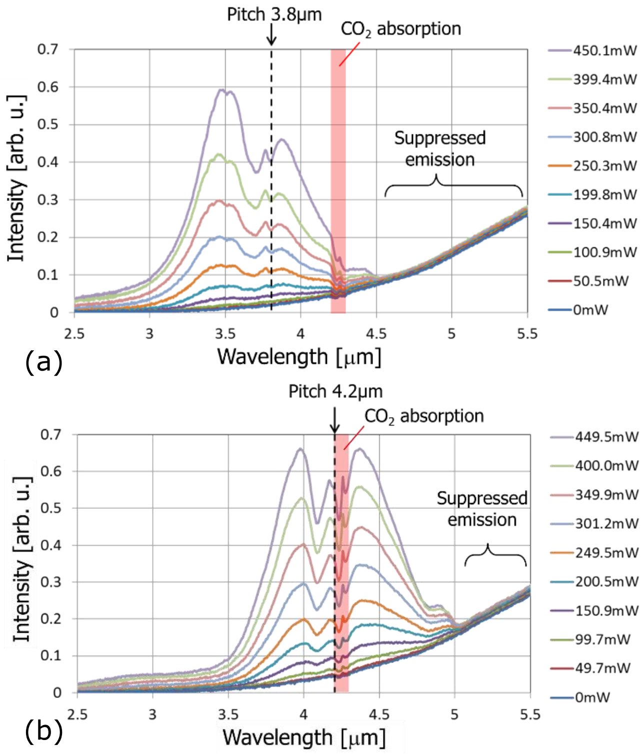

Fig. 6: FT-IR spectra of the emission using the commercially available blackbody emitter. The gratings are designed based on (a)2D and (b) 3D models.

4. Fabrication

The fabrication is Si etching by 0.4μm and Au deposition. During the process, the line width is measured. The oxidation and the oxide etching is carried out two times. The oxidation consumes Si by 44% of the oxide thickness, and the duty ratio becomes smaller. The oxide thickness can be controlled at sub-μm level. At the same time, Si surface becomes smoother. Figure 5 includes SEM image of the grating. The difference between the design line width and the average of the actual one is within 0.04μm. The standard deviation is within 0.1μm. 20 points are measured at 5 areas in 3-inch wafer.

5. Infrared emission experiment

Figure 5 shows the experimental setup for checking the emission spectrum using the fabricated grating. The commercially available blackbody emitter (EMIRS200, Axetris) is used, although the heat recycle effect is subtle, because our original microheater is under the development. One side of the package can is cut off for opening the SPP path.

Figure 6(a) is the emission spectra obtained using the grating designed based on 2D model. There are peaks from 3.0 to 4.5μm. The longer wavelength is well suppressed. The red region shows the CO_2 absorption band. The main peak is at shorter wavelength. Figure 6(b) is obtained using the grating designed based on 3D model. The center of the emission peak agrees well with the CO_2 absorption band showing the consistence with the analysis.

6. Conclusions

Au grating that excites SPP is analyzed and designed so as to include the absorption wavelength of CO_2 gas. Duty ratio and grating depth are found to be the important design parameters. Counting azimuthal ϕ in 3D model, which shorten emission wavelength compared to that of 2D model, the observed emission includes CO_2 absorption at the center.

Acknowledgements

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References

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