Proposal of Two Tangent Hole Structure for Higher Sensitivity Gas Sensor

I-EggS (Interdisciplinary Graduate School of Engineering Sciences), Kyushu Univ.,

Zan Hui Chen○, Wenying Li, Yu Han, Haisong Jiang, and Kiichi Hamamoto

E-mail: zan.hui.861@s.kyushu-u.ac.jp

1. Introduction

Silicon photonic crystal cavities (PhC) with high-quality factors are very sensitive to the changes in the dielectric properties of their surroundings. Utilizing this high sensitivity, it is used for the ultrasensitive gas sensor [1], One problem, however, for typical PhC structures, the sensitivity (S) is low because the analyte is located in the air or liquid region where the strength of the confined light field fully overlaps with the analyte. Therefore, the gas detection sensitivities of most geometries are generally limited to around 0.3-0.67 nm/% [2, 3]. To overcome this problem, we propose a photonic crystal cavity consisting of a bus waveguide and the tangent air hole array. Based on this design, which tightly confines light in the air region where it fully overlaps with gas molecules, to improve the gas detection sensitivity. Theoretical analysis reveals that the methane gas detection sensitivity significantly improved to 2.16 nm/%.

2. Concept of one-dimensional photonic crystal cavity with two tangent hole structure (1D PhCC-TAH)

A schematic of the design of 1D PhCC-TAH structure is shown in Fig. 1 (a). In this structure, there are 21 tangent air holes with 100 nm radii (R_1) for the central cavity and the 15 tangent air holes with 120 nm radii (R_2) as a mirror on each side of the cavity. The photonic crystal lattice spacing is Λ=600 nm and the width of the waveguide is 500 nm. It has reported that the parameter of hole radius, periodicity and mirror numbers be optimized using the algorithm [4]. Figure 1 (b) shows the radius size of air hole variation to the position of tangent air holes along waveguide. The structure is designed with a 260 nm silicon device layer and 5 μm thick silicon dioxide layer. The new design allows the light field confined in the gap between two open space holes, which corresponding to the optical energy is progressively squeezed into a smaller volume to improve the sensitivity of gas detection.

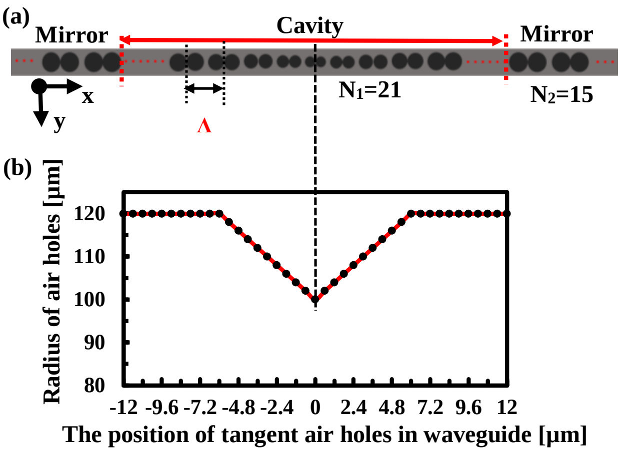

Fig. 1. Design of 1D PhCC-TAH structure. (a) Schematic illustration of the 1D PhCC-TAH structure, the width of the waveguide is 500 nm, the periodicity Λ is 600 nm. (b) Plots of radius size of air hole variation to the position of tangent air holes along waveguide.

3. Results and Analysis

For the previously reported single air hole structure, the optical resonance mode is the dielectric mode where the light field with the strongest optical intensity is localized inside the dielectric, while gas molecule is located in the open space hole where the light field does not intensively overlap with gas molecule. As a result, the methane gas detection sensitivity of most geometries are generally limited to 0.67 nm/% [3], as shown in the Fig. 2.

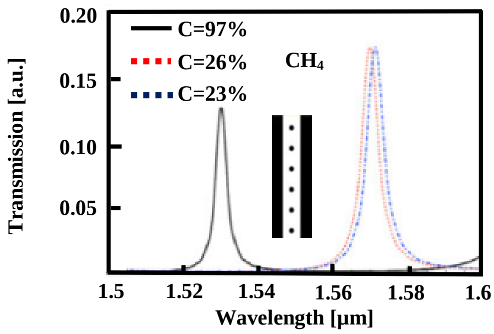

Fig. 2. The sensitivity of the single air hole structure [3].

By introducing two tangent air hole structure, the 1D PhCC-TAH structure tightly confines light in open space hole where it overlaps with gas molecule, which improve the sensitivity of gas detection. Figure 3 exhibits the sensitivity of the 1D PhCC-TAH structure. As seen, the methane gas detection sensitivity is calculated as 2.16 nm/%. In addition, the overall FOM of our designed 1D PhCC-TAH structure is 1.2×10^4. With respect to the single air hole structure, the proposed 1D PhCC-TAH is simultaneously achieved high sensitivity (2.16 nm/%) and figure of merit (FOM=1.2×10^4).

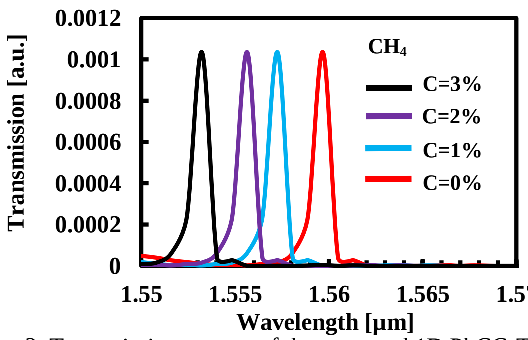

Fig. 3. Transmission spectra of the proposed 1D PhCC-TAH when the methane gas concentration changes from C=0% to C=3%, T=300k.

At presently, the research work of one-dimensional photonic crystal cavity based on multiple cascaded air hole structure has not been studied. Next, we will carry on the research work of photonic crystal cavities with 3 or 4 cascaded air holes, to compare the optical performance with previous structures.

4. Conclusion

We have proposed a 1D PhCC-TAH structure, which tightly confine light in the air region where it can fully overlap with gas molecules, to improve the gas detection sensitivity. The methane gas detection sensitivity was significantly improved to 2.16 nm/%.

Acknowledge

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References

[1] D. F. Dorfner et al, Appl. Phys. Lett. 93, 181103 (2008).
[2] W. C. Lai et al, Appl. Phys. Lett. 102, 041111 (2013).
[3] K. Hirai et al, Jpn. J. Appl. Phys. 53, 04EG09 (2014).
[4] Q. Quan et al, Opt. Express., 19, 18529-18542 (2011).