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3-5 ㎛ 적외선 흡수체를 가진 전면 건식 식각된 서모파일과 NDIR CO_2 가스 센서의 응용

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A Front-side Dry-Etched Thermopile Detector with 3-5 ㎛ Infrared Absorber and Its Application to Novel NDIR CO_2 Gas Sensors

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Abstract - We present a front-side micromachined thermopile with high sensitivity in the 3-5㎛ window, and discuss its application to a novel non-dispersive infrared (NDIR) CO_2 gas sensor with a light source emitting collimated light. The micromachined thermopile shows a measured sensitivity of 30 mV/W and a D^* of 0.3×10^8cm√Hz/W. Using this newly fabricated thermopile, we also have successfully developed a small, sensitive NDIR CO_2 detector module for accurate air quality monitoring systems in energy-saving building and automotive applications. The novel sample cavity comprising specular reflectors around the light bulb is configured to uniformly emit collimated light into the entrance aperture of the cavity in order to enhance the sensitivity of NDIR CO_2 detector.

1. Introduction

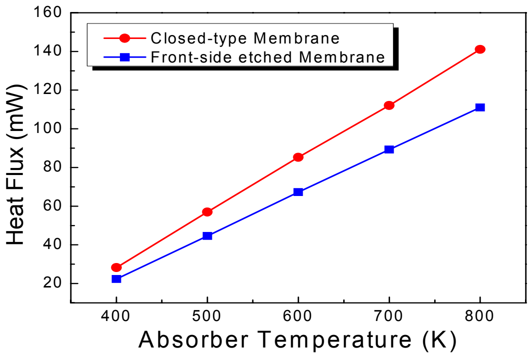
Non-dispersive infrared gas sensors have widely been used to detect CO_2 gas. A variety of thermopiles have already been fabricated and commercialized for NDIR application[1]. The traditional thermopiles have been designed to operate in the 8-14 ㎛ wavelength range, so that they have low sensitivity at absorption wavelength of CO_2 (=4.26㎛). Furthermore, in order to thermally isolate the hot junctions of the thermopile from the silicon substrate, commercial thermopiles commonly used closed-type membrane and metal black as absorber material. But the closed-type membrane flows more heat flux than bridge structure and metal blacks still have some significant issues such as high fragility and low reproducibility[2].

In this paper, we designed and fabricated the thermopiles consisting of a bridge structure using XeF_2 dry etching process and a thin-film IR absorber with high absorption (over 90%) in 3-5 ㎛ wavelengths. Also, as it's application, the novel sample cavity comprising specular reflectors around the light bulb is configured to uniformly emit collimated light into the entrance aperture of the cavity in order to enhance the sensitivity of NDIR CO_2 detector.

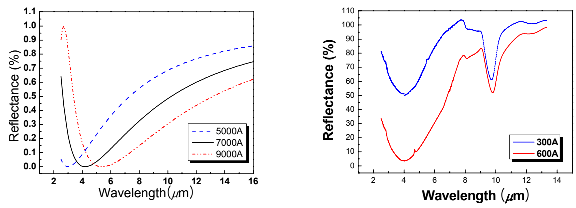
2. Experiments

We simulated the distribution of heat flux on the closed-type membrane fabricated by back side silicon etching and the front-side dry-etched membrane(this work) using Coventor Ware. Figure X shows the simulated results. The slopes of the heat flux for a closed-type membrane and front-side dry-etched membrane are 280 ㎼/K, 220 ㎼/K respectively. The heat flux of front-side dry-etched membrane has much lower slope than closed-type membrane.

The simulation results for an IR absorber indicated that effective absorption more than 90% in 3 to 5 ㎛ wavelength range will be obtained when the structure has a SiO_2 thickness of 7000Å and a metal sheet resistance of 400 Ω/sq. (Fig.2(a)) As shown in Fig. 2, IR reflectance spectra for a thin-film absorber, obtained using a FT-IR spectrometer, is quite close to the simulation results. The 600Å-thick absorber has the least reflectance around the 4.0㎛. Only 3.5% of the incident radiation is reflected from the stacked film at this wavelength. The reflectance in the rage between 3.0 and 5.0㎛ is less than 10%. Although there is not a perfect match to the sheet resistance of free space, the absorption is good.



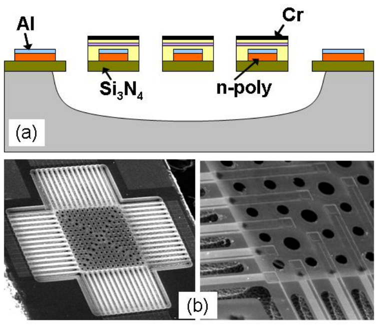
<Fig.1> Thermal simulation results.



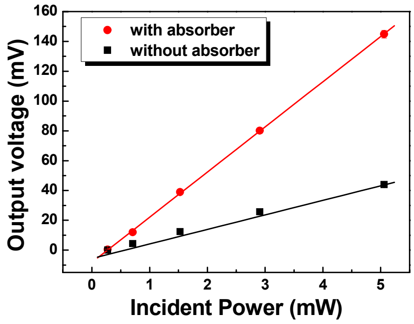
(a) (b)

<Fig.2> (a)Calculated spectral reflectance of IR absorber structures and Measured reflectance spectrum.

Based on these simulation results, the thermopile sensor depicted in Fig.3 was designed and fabricated. Figure 4 shows the relationship between output voltage and calculated incident power. The thermopile have a measured sensitivity of 30 mV/W, a resistance of 170 kΩ, and a D^* of 0.3×108 cm√Hz /W.

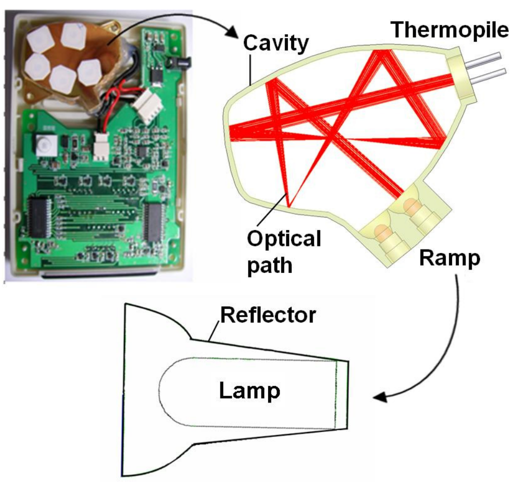


<Fig.3> (a) Diagram of the thermopile design and (b) SEM images of a completed thermopile chip



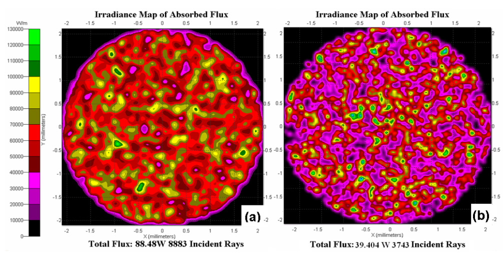
<Fig.4> Measured output voltages of thermopiles with and without absorber.

This newly fabricated thermopile was applied to the development of a smaller, more sensitive NDIR CO_2 sensor compared to existing detectors (Fig.5). Figure 5 show newly developed NDIR CO2 gas sensor. It consists of signal processing part and optical cavity with thermopile detector and IR lamp.



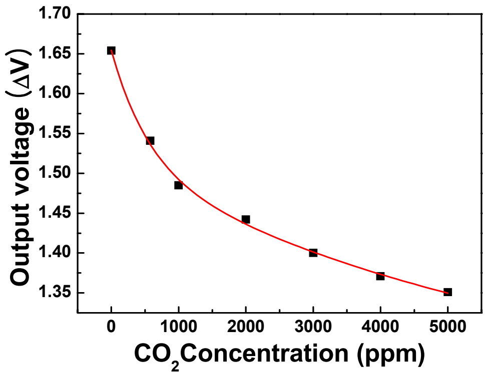
<Fig.5> Photograph of a newly developed NDIR CO_2 Detector; It has (a) a novel gas sample cavity comprising (b) specular reflectors around the light bulb.

Figures 6(a) and (b) show a comparison of the radiation distribution incident on the thermopile within the newly designed cavity (Fig.5).



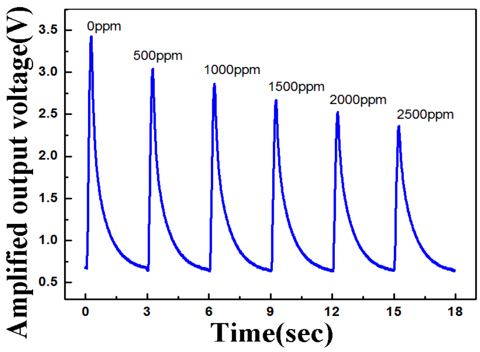
<Fig.6> Simulation results of incident radiation on the thermopile. (a) this work and (b)existing sensor

For the optical path length of 20 cm, the amount of incident radiation on the thermopile in the sample cavity with the newly designed lamp was about 94% of the total irradiance, about 20 times higher than that from a existing sensor, resulting in the enhanced sensitivity, as shown in Fig. 7.



<Fig.7> Output characteristic of sensor module.

Figure 8 shows the dynamic response of the NDIR sensor exposed to various concentrations of CO_2 gas. Key features of newly developed both thermopile and NDIR CO_2 detector are that they are very stable with repeatability and fast response time.



<Fig.8> Dynamic response to CO_2 gas at various concentrations.

3. Conclusions

Design and fabrication of a front-side micromachined thermopile with 3-5 ㎛ infrared absorber has been described. The three-layer film absorber has an absorptance of over 90% in 3.3-4.9 ㎛. For a thermopile with multi-layer absorber, the output voltage was found to be 144.83 mV at 5 ㎽ incident power, approximately 3.29 times compared to that of one without absorber. The thermopile with three-layer film absorber showed a measured sensitivity of 30mV/W, a resistance of 170 kΩ, and a normalized detectivity of $0.3X10^8 cm\sqrt{Hz}/W$. For the optical path length of 20 cm, the amount of incident radiation on the thermopile in the sample cavity with the newly designed ramp was about 94% of the total irradiance, about 20 times higher than that from a existing sensor, resulting in the enhanced sensitivity.

ACKNOWLEDGMENTS

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[References]

[1] A. Graf *etal.*, "Review of micromachined thermopiles for infrared detection," Meas. Sci. Technol. Vol.18, pp.R59 - R75, 2007.

[2] M. P. Thompson *etal.*, "Infrared absorber for pyroelectric detectors,"Meas. Sci. Technol. Vol.18, pp.R59 - R75, 2007.