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Controlled Thermal Emission of Narrow-band IR Waves for Downsizing Sensor Module

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1. Introduction

Mid-IR (MIR) region plays essential roles in spectroscopy and environmental monitoring applications as the substances have unique absorption peaks in that region. Optical detections are characterized as robust and long term stable sensing. Despite the importance, the IR emitters for MIR region mainly rely on blackbody radiations. As stated in Planck's law, spectrum of the blackbody is determined as a variable of temperature [1] and characterized as a broadband emission. As for portable sensors, thermal IR detectors and narrow-band optical bandpass filters (BPFs) are commonly used as wavelength selective detections. These discrete compositions hinders downsizing. BPFs consist of several dozens of dielectric layers and qualities of each layer will affect transmission properties [2]. In some cases, extra compensation may be required to ensure the accuracy.

The conventional sensors only use a small portion of the input power for sensing. Incandescent light bulb, blackbody emitter radiating broad spectral IR, consumes several dozens or hundreds of milliwatts. Large percent of the broad spectral IR is not used for sensing. This decreases the power efficiency. Improvements are strongly required, especially for long life portable sensors. Recently, metallic periodic structures having sizes nearly equal to wavelength of IR, known as plasmonic thermal emitters (PTEs) [3-5], are promising candidates for replacing the conventional emitter and BPFs.

In this study, we propose a new wavelength selective IR emitter. Wood's anomaly, which occurs in shallow metallic groove at the wavelength same as the pitch of the structure for normal incidence, is used first for IR emitter. A centimeter-sized verification model is fabricated. Emission peak at wavelengths nearly equal to the period of the groove is observed. Combined with the coverage of Au film, the emitter temperature is observed to increase higher with lower input power, showing suppressed loss due to the blackbody emission.

2. Fabrications

Fig. 1 shows the fabrication process of Au groove. Si wafer (20×20×t0.4 mm) is used (step 1). Line & space pattern having a period of ~1.67μm (600 line/mm) is transferred to the polished side. Patterned area is 12.7 mm×~18 mm. Si etching is carried out with RIE (step 2), then the photoresist is removed. Average depth is ~0.25μm. Au is deposited following Cr deposition by thermal evaporation (step 3). Thicknesses of Au and Cr layers are 75 nm and 7.5 nm, respectively.

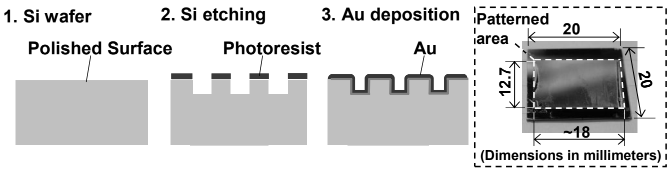

Fig. 1 Fabrication sequence of a Au groove. The inset shows image of the fabricated structure.

Fig. 2 shows an emitter assembly, which consists of fabricated Au groove, a heater sub-assembly, and IR reflectors. The heater sub-assembly consists of NiCr wire heater sandwiched between Si substrates. Au groove is faced to heater sub-assembly with 0.5mm gap. Au groove is set with the offset of ~2 mm, so as to allow the emission. Stacked heater and Au groove are sandwiched with IR reflectors and strapped to mounting plate with stainless steel wires. The entire assembly is suspended from the mounting plate with wires to minimize the thermal conduction loss.

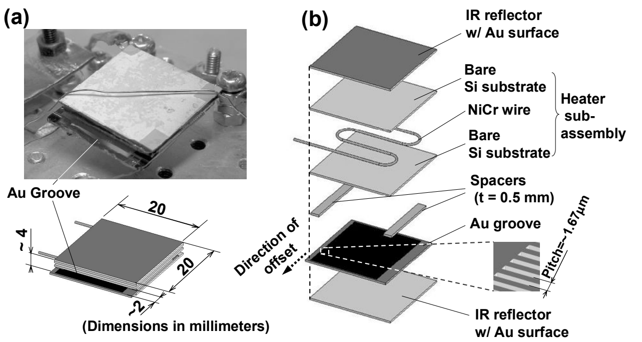

Fig. 2 a) Actual and schematic diagram of the emitter assembly. b) Exploded view.

3. Experiment

Fig. 3 shows the experimental setup for measuring spectra. The emitter assembly is placed inside a vacuum chamber with a BaF_2 window and kept at vacuum pressure ~5 Pa. Heater temperature, measured with a thermocouple located on the backside of heater sub-assembly, is controlled at 300°C. IR from the emitter enters an aperture with a slit width of ~2mm. IR enters monochromater equipped with a grating (blaze wavelength: 2μm). Modulated at 700Hz with an optical chopper, IR is polarized and enters an IR detector (Hamamatsu R4638 PbS detector). Detector output is read out with a lock-in amplifier (NF LI5640) and data is acquired with a PC, which controls wavelengths of monochromater.

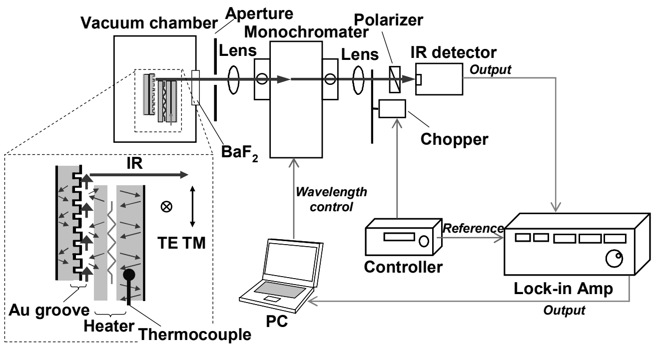

Fig. 3 Experimental setup for measuring emitter spectra.

4. Results and Discussions

Fig. 4 shows emission spectra from fabricated emitter for a) TM and b) TE polarizations. Emission spectra from Au groove (close circle) and Au mirror surface right above NiCr heater (open circle) are shown. Broad peaks at λ=~2600nm can be attributed to the intrinsic spectral sensitivity of the PbS detector (λ_{peak}=~2.5μm) and the efficiency of the monochromater. For TM polarized emission from Au groove, peaks are at λ=1580nm and 1730nm and their Q-factors are 26.2 and 34.6, respectively. For TE polarization, peak is at λ=1590nm and Q-factor is 8.4.

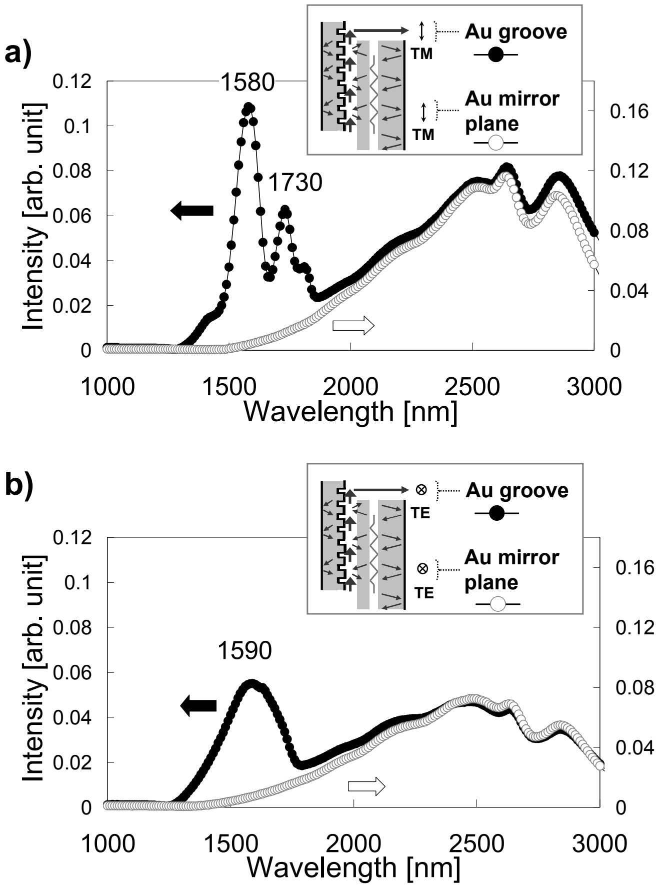

Fig. 4 a)TM and b)TE polarized emission spectra. Emission from Au groove (Close circles) and Au surface (Open circles).

Fig. 5 shows heater temperature as a function of input power. Temperatures are read after the saturation of the temperature response. Conditions of emitter assembly are 1) with Au groove and flat surfaces, 2) with Au flat surfaces, and 3) all components of the assembly replaced with bare Si, as shown in insets. Required powers to raise heaters to 290°C are 1) 3.8W, 2) 3.1W, and 3) 6.2W.

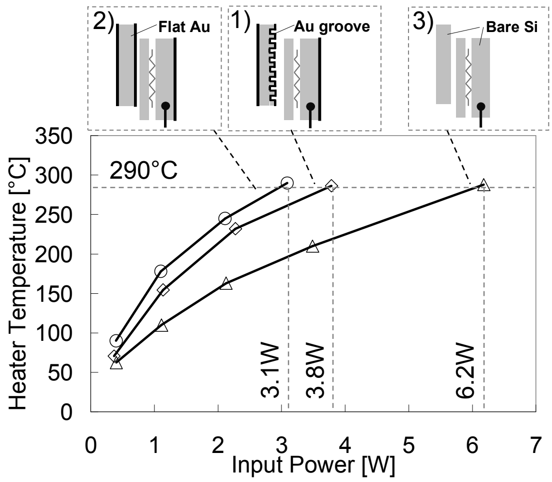

Fig. 5 Input power dependence emitter assembly 1) with Au groove and flat surfaces (diamonds), 2) Au flat surfaces (circles), and 3) all components replaced with bare Si (triangle).

4. Conclusions

New narrow-band wavelength selective IR emitter using Au groove is proposed. The verification model emitter showed radiance peak at λ_{peak}=~1.67 μm, which correspond to Wood's anomaly of the groove. Au reflectors are considered to trap heater power inside the emitter, preventing thermal radiation loss of the blackbody. The power efficiency is observed to be improved.

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