To design antennas for mid-infrared (MIR) hot electron bolometer mixer (HEBM), the complex surface impedance of Au thin films at cryogenic temperatures was evaluated using Fourier transform infrared spectroscopy (FTIR) with resonator arrays that were constructed by Au thin film strips. By fitting the measured resonant frequency to simulated results, the corrected surface reactance was established. MIR HEBM that were constructed with slot antennas and distributed circuits were designed and fabricated using the corrected surface impedance. The design frequency was 61 THz. The HEBMs were formed as a superconducting strip with Au antennas and electrodes. For evaluating the mixer properties, measurement setup was constructed. In this setup, local oscillator power was applied directly from the vacuum side to the HEB and the signal was applied from the substrate side though the focused optical. We confirmed that the critical current of the HEB can be reduced to be about 0.8 GHz by using the CW-MIR-light response. IF output power characteristics of the MIR HEB mixer were also observed, and the slight difference of the IF output power between 1100 K and 300 K thermal loads was confirmed.

I. Surface impedance correction of gold under cryogenic conditions

Because of the mid infrared light range is at the region of occurrence of anomalous skin effect, the complex surface impedances of the Au films were needed for the simulation of MIR circuits. The impedances were derived using the measured reflective indices. However, these derivations were insufficient for designing superconducting MIR devices. Therefore, we corrected the surface impedance at cryogenic temperatures by using a FTIR with sample cooling system.

II. Design of mid-infrared twin-slot antenna with Xc correction

By using the corrected surface impedances, the antenna size was designed using the Sonnet EM simulator for operation at approximately 60 THz.

The measured detector width and length were approximately 0.26 and 0.18 μm, respectively. In the I/V characteristics, there are two critical currents (Ic). We consider that there are two different superconductivity regions. One is the strip near the metal electrode affected by Ni, and the other is the region without the influence of Ni. Two transition temperatures associated with these 2 regions (Ic1 and Ic2) were observed at 5 K and 11 K. The measured normal resistance of the HEB was approximately 200 Ω.

III. Fabrication of MIR HEBM with a twin-slot nano-antenna

1. Study of MIR-HEBM structure using NbN

2. Fabrication of MIR-HEBM

We developed a new fabrication process using electron beam lithography for all of our lithography processes.

IV. Evaluation of MIR HEBM

1. Measurement setup for MIR-HEBM

A mid-infrared quantum cascade laser (QCL) was used as the local oscillator. Here, the wavelength was 4.89 μm. The polarization of the LO was dicted by “Polarizer 2”. Certainly, the antenna gain directly is strong substrate side, but it remains also on the vacuum side. In MIR region, the dielectric constant of Mo薄膜 was reduced to be about 2.66. Radiation power ratio of the substrate direction P1 and the vacuum direction P2 of the slot antenna formed on a thick dielectric substrate can be expressed as follow:[ref]

2. Irradiation power dependency of I/V characteristics

The LO-suppressed to almost zero by LO irradiation, and it was found that sufficient power can be given to HEBM even with LO irradiation from the space side.

3. Output waveform under CW-MIR-light irradiation

First, the HEB is biased close to Ic. By the irradiation of mid-infrared light, the detection temperature will be increased and Ic will be reduced. When the Ic is reduced less than the bias current, the output voltage will be observed. Due to fluctuation of the CW MIR light, the voltage pulses were observed under constant current bias. The full width at half maximum of averaged pulse was observed about 0.21 μs. Assuming that the response characteristics of the HEB can be represented by the LPF model, the impulse response was about 0.21 μs and it was expected that the IF bandwidth was about 0.8 GHz.

IV. Future tasks

- Reduction of noise of voltage bias source.
- Evaluation of the receiver noise temperature and IF-bandwidth at mid-infrared region.