Study on Terahertz Bolometer with High-Impedance Antenna

（Doctoral qualification by coursework, Form 7）

Abstract of Dissertation

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Abstract：

Frequency spectrum from 0.1 to 10 THz has been associated with the terahertz (THz) range. It is the transition region from radio−electronics to photonics. In the frequency range around 1 THz, the intermolecular vibration of prevalent molecules and chemicals formed a unique absorption characteristics known as the THz fingerprints. This distinctive feature has aroused great interest among many scientists, leading to advances in the THz research and development. Numerous THz applications are emerging in the recent decade such as the next generation high-speed wireless communication, non-destructive testing, food and water inspection, cancer detection in human tissue, and remote sensing for weather forecast. However, the lack of commercially available high-power sources and high-sensitivity detectors have made this region also known as the "THz gap" in terms of the radiating and sensing capability. Therefore, the development of high-performance THz sources and detectors is necessary.

As one of kind THz detectors, thermal detector is favorable due to the small wavelength dependency, low cost, and room-temperature operation. Sensitivity of thermal detectors is affected by the thermal conduction to the supporting structures such as substrate and the surrounding environment. Hence it is important in the design of thermal detectors to assure low thermal conduction by making a suspended structure with long and narrow supporting legs. However, longer wavelength in the THz region makes such thermal isolation difficult, and the antenna-coupled detector becomes a viable solution, in which only the heater/thermistor part is thermally isolated.

A novel THz bolometer consisting of antenna and suspended titanium heater/thermistor on oxidized silicon substrate has been studied. Previously, the meander thermistor with fourfold higher resistance could attain twofold higher responsivity compared to the straight one. However, the heater resistance was kept low considering the impedance matching with a low-impedance half-wave dipole antenna. As a result, the noise equivalent power (NEP) could not be improved (reduced) due to the high thermal conductance of the low-resistance heater, although the responsivity was improved.

In this study, a further enhancement is attempted by introducing high-resistance heater with narrow width. To maintain optimum power transfer between antenna and heater, high-impedance folded-dipole antenna (FDA) has been introduced. Firstly, for various number of

arms N, antenna width W_a, and space between arms S, the antenna impedance is simulated to adjust the antenna length so that the imaginary part of the impedance becomes zero, and to obtain the resonance resistance R_r. Secondary, the absorption efficiency for the heater resistance R_r is simulated to calculate the product of the efficiency and the Rr, which is the figure of merit (FOM) under the assumption that the thermal resistance is proportional to the heater resistance. The optimum FOM, which is 15 times larger than that of the half-wave dipole antenna, is obtained for N=3, W_a=1μm, S=4μm and R_r= 675 Ω.

The proposed design is then fabricated with electron beam lithography. Multiple devices with different heater resistances ranging from 92 to 1122 Ω are prepared. Electrical characterization reveals that the responsivity and NEP can be enhanced by a factor of 2.5 as the result of the increase in heater resistance. Furthermore, optical characterization of the FDA-coupled and half-wave dipole antenna-coupled bolometers by 1-THz source is performed by illuminating the bolometer chip installed in a vacuum dewar, with the optical input power calibrated by a commercial pyroelectric detector at the same position. In this measurement, the heater resistance is optimized separately for both kinds of antenna. As a result, the FDA coupled with the high resistance heater can realize higher responsivity and lower NEP by a factor of 1.6 compared to the half-wave dipole antenna coupled with low resistance heater. Optical measurement with various heater resistance confirms the effective power transfer by proper impedance matching between the antenna and heater.

In addition, the bolometer thermal parameter analysis is attempted based on a simple thermal equivalent circuit model. The total thermal resistance of the bolometer consisting of the heaters with various electrical resistances and other part with a fixed thermal resistance is assumed. The extracted thermal resistance of the proposed model reproduces the electrical measurement results well. As for optical measurement, a model is proposed, in which the antenna is regarded as a voltage source with an internal resistance. The model can qualitatively explain the behavior of the optical responsivity and NEP with respect to the heater resistance for both types of antenna.

In conclusion, the comprehensive electrical and optical characterizations in this study suggests the importance of the higher heater resistance for simultaneous enhancement of responsivity and NEP in the bolometer. Application of high-impedance antenna is also important for the optimum power transfer between antenna and heater in optical characterization. The fitting results extracted by the proposed model reveals the importance of thermal conductance reduction by eliminating the thermal conduction by the parts other than the heater. This could be accomplished by the use of a single metal film as an integrated heater and thermistor as well as removing the silicon dioxide inter- and bottom-layers.