Study on Metal- and SOI-CMOS-Based Antenna-Coupled Bolometers for Terahertz Detection

（課程博士・様式７）（Doctoral qualification by coursework, Form 7）

学 位 論 文 要 旨

Abstract of Doctoral Thesis

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論文題目：テラヘルツ検出のための金属ならびに SOI-CMOS に基づくアンテナ結合ボロメータの研究

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Abstract：

Exciting features of terahertz (THz) region (300 GHz – 3 THz) in the electromagnetic spectrum incite numerous applications such as security screening, non-destructive testing, drug detection and industrial quality control, high data rate communication, astronomy and medical imaging. The wide scope of THz technology enhances the development of highly sensitive, cost-effective and room-temperature operable THz detectors. However, this region is often called as "THz gap" due to the lack of consumer products with reasonable performance. Furthermore, for THz imaging applications the detectors should have planar structure and easily be arrayed. To resolve the afore-mentioned issues, antenna-coupled bolometer structure have been developed by placing the integrated heater-thermistor structure at the center of a half-wave dipole antenna. Narrow-width (0.1 and 0.2 μm) titanium (Ti) and platinum (Pt) thermistors were introduced to reduce thermal conductance (G_t) and increase electrical resistance (R_0). Additionally, complex layout pattern such as, meander shape, was adopted to increase the effective length, leading to larger R_0 and responsivity (R_v). Ti and Pt were selected as possible candidates of thermistor material because of the low thermal conductivity for the former, and high resistance to oxidation and standard use as a temperature sensing material for the latter. To check the effectiveness of meander pattern, straight wire thermistor was also fabricated on the same chip. The performances of both Ti and Pt with straight and meander thermistors were analyzed, where the narrow Ti thermistor (0.1 μm) with meander pattern showed better R_v, noise equivalent power (NEP) and response time (τ) of 788 V/W, 185 pW/√Hz and 19.4 μs, respectively. The performances were compared with respect to the thermistor length for both straight and meander thermistors. The "nominal" length (11.5 μm) is plotted for the meander thermistor (0.1 μm) considering the importance of the "footprint" for the application to antenna-coupled bolometer. Meander thermistor showed better performances than straight wire bolometers in terms of R_v, NEP and τ. Although the Ti meander thermistor showed better R_v, the sensitivity should be further improved for wider applications.

Therefore, to enhance the performance of bolometer, the effect of Joule heating (annealing) was studied on Ti straight thermistors by reducing its crystalline defects. Ti straight wire thermistors formed by patterning of electron-beam evaporated Ti thin film using laser lithography and liftoff, followed by the deep cavity formation for better thermal isolation. Noticeable change in thermistor R_0 14 times larger than the initial one was observed after employing Joule heating. Negatively large temperature coefficient of resistance (TCR) of -0.32 %/K was also observed after the treatment while initial TCR was 0.19 %/K. As a result, R_v was improved 4.5 times from the pristine one. Still, Ti thermistor suffers from low-integration level, which needs to be improved for the development of focal plane array with readout integrated circuits. This highly necessitates the development of THz detector compatible with integrated circuit process. Hence, silicon (Si)-based antenna-coupled bolometer have been investigated for THz detection. The major advantages of Si CMOS technology are the good reproducibility and the universality of the results. Silicon-on-insulator (SOI)-CMOS-based antenna-coupled bolometer with different temperature sensors such as, MOSFET, pn-junction diode, Si resistor and thermocouple were designed by adopting antenna-coupled structure which provides the integrated heater-thermistor area of 15 μm × 15 μm. Temperature sensors were fabricated by using the standard commercially available 0.6 μm SOI-CMOS technology without introduction of exotic materials. Performance estimation in terms of R_v showed the largest value of 6.27 kV/W for n-channel MOSFET. The smallest τ of 2.34 μs was obtained for the resistive bolometer whereas the MOSFET showed 13.8 μs. One order of magnitude smaller NEP (202 pW/$\sqrt{\text{Hz}}$) than that of the resistive bolometer was estimated for the MOSFET. In general, Si has a relatively high thermal conductance due to the lattice conduction, and this degrades the R_v and NEP. Considering the overall performance, current results suggest that the THz antenna-coupled bolometer with n-channel MOSFET at the center of an antenna can be a promising detector for the electromagnetic waves around 1 THz, which is useful for transparent imaging and material identification. The investigation of this thesis evolves from the analysis of metallic bolometers to SOI-CMOS-based bolometers for THz detection. In the first part of the thesis, the structure and characterization methods of antenna-coupled Ti and Pt bolometers with meander and straight wire thermistors were explained. Performance evaluation in terms of R_v, τ and NEP were discussed for both meander and straight thermistors. The length dependence of performance metrics were analyzed and compared. Joule heating was employed on Ti straight thermistors to enhance the performance. In the next chapter, the SOI-CMOS-based bolometers with various temperature sensors (MOSFET, pn-Junction diode, Si resistor and thermocouple) were evaluated for THz detection. The fabricated devices were designed structurally based on a few assumptions by adopting 1-THz antenna-coupled structure. The performance estimation of each temperature sensor is discussed under common constraints. The overall results suggest that n-channel MOSFET bolometer can be a promising THz detector integrable with SOI CMOS technology.