論 文 の 内 容 の 要 旨

論文題目　　Strain tuning and piezoresistive detection in MEMS beam resonators for terahertz bolometer applications

（テラヘルツボロメータ応用に向けたMEMS梁共振器構造における歪みチューニングとピエゾ抵抗効果に関する研究）

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In this thesis, effect of internal strain and detection scheme on doubly clamped MEMS beam is investigated for THz bolometer applications. Previously, we reported a very sensitive bolometer structure by using a GaAs doubly clamped beam resonator. The MEMS resonator detects THz radiation by measuring a shift in its resonance frequency induced by heating of the MEMS beam due to THz absorption. Speed of the device can be up to 10kHz, which is much faster than other kinds of room temperature THz thermal sensors. The MEMS bolometers are superior to other room-temperature THz bolometers, but still not comparable with the low temperature detectors in aspect of the sensitivity and speed.

In order to realize a high sensitivity, high speed MEMS bolometer for THz detection, a common method to modify the speed and sensitivity is to change the thermal conductance of the MEMS beam. A small thermal conductance of the bolometer

indicates a large temperature rise and good sensitivity, but the thermal time constant also increases which means a low detection speed. Such a trade-off always exists and limits the performance of common bolometers.

In this thesis, we have proposed to obtain the high sensitivity and high speed of the MEMS bolometer by using short InGaAs MEMS beam detected by piezoresistive detection. This method can evade the speed-sensitivity trade-off of the MEMS bolometer. Changing the beam material to InGaAs provides a high thermal responsivity, the short MEMS beam provides a high speed and the piezoresistive detection provides a large output voltage.

Outline of this thesis is shown as follows.

In Chapter 2, the operation principle of the MEMS bolometer is explained. In this work, a GaAs doubly clamped MEMS beam resonator is used to detect THz radiations. When the beam is heated by THz radiation, the temperature rise is detected as a resonance frequency shift of the beam. A long beam has a small thermal conductance. It can keep the THz heat and show a high responsivity but a low speed. Such a trade-off exists and we cannot obtain the high sensitivity and high speed at the same time.

In Chapter 3, origins of a deflection in the MEMS beam are discussed. Such a deflection brings difference from the theory to the experiment result of the MEMS bolometers and makes it difficult to predict the devices' performance. We found that there are two factors that induce the beam deflection. First is the initial bending of the MEMS beam. To reduce the bending, we introduce a tensile strain to the MEMS beam using GaAsP as the beam structure and finally we reduced the deflection from 150 nm to 50 nm. Another reason of the beam deflection is a step structure on the beam surface. The step structures are used for driving and detection of the beam vibration. We reduced the step height and finally the deflection is reduced to as small as 10 nm. Fabrication and measurement of the MEMS beam is also introduced in this chapter.

In Chapter 4, we propose to enhance the responsivity of the MEMS bolometer by preloading a critical buckling strain. With the deflection of the beam reduced to 10 nm, the beam is nearly ideal and shows a high responsivity around its buckling point, as predicted in the theory. To achieve this high responsivity, we preload a critical buckling strain to the beam through lattice mismatch between InGaAs and the GaAs substrate.

Preloading such a strain does not change the thermal conductance of the beam, so it can evade the speed-sensitivity trade-off. Finally we achieve a 15-time-enhancement of responsivity. Also, the noise density of the bolometer is introduced and, we demonstrated that the noise density of the strained beam has strong dependence on its vibration amplitude.

In Chapter 5, we will discuss the detection scheme of the MEMS beam vibration. Since the speed-sensitivity trade-off is evaded, short beams can exhibit a high sensitivity and high speed at same time. However, the piezo-capacitive detection of the present device is not suitable for detecting vibration of short beam, because the output voltage from the piezoelectric capacitor is shunted by the stray capacitance of measurement cables and shows smaller than 1 μV. Therefore, we need to develop another detection scheme. Piezoresistive effect is suitable for the detection of the short beams. Since the resistance is determined by L/W ratio of a resistor, the output voltage is not affected be the beam length decrease. We designed MEMS beams with piezoresistive detection, and tried NiCr film, 2D electrons and 2D holes as piezoresistive materials. Results shows that by using 2D holes as the piezoresistive material, the output voltage increases to as large as 10 mV which is 10000 times of that of the piezo-capacitive detection. Also, effect of the source voltage and the crystallographic orientation is discussed. both of which has influence on the detection performance.

In Chapter 6, a conclusion and an outlook for future development is also given.