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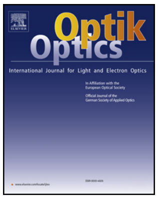

Original research article

Microbolometric theoretical responsivity analysis for focal plane array under pulse current bias

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ABSTRACT

Based on the physical thermal balance equation of the microbolometer under pulse current bias, the microbolometric theoretical infrared responsivity is given out in this paper. The operating temperature of the microbolometer during the pulse current bias period is theoretically discussed and analyzed, from which the microbolometric theoretical infrared responsivity expression is derived for high-speed microbolometric focal plane array. The microbolometric theoretical infrared responsivity expression reveals some key factors to decide the infrared sensitivity of the microbolometric focal plane array and has been successfully verified through an experimental microbolometric focal plane array. The microbolometric theoretical infrared responsivity expression is theoretically strict and can be utilized for future microbolometric focal plane arrays with some high-performance characteristics parameters such as high-speed and small-pixel.

1. Introduction

With the development of fabricating processes for sensor array and readout integrated circuit technologies, microbolometric focal plane arrays are enough for many applications [1–3], but there are still some common requirements for low-power, low-noise, small-pixel, and high-speed infrared image systems [4–6]. When the sensor array of a microbolometric focal plane array is irradiated by the incident infrared radiation from an imaging target, its microbolometric resistances are changed due to the infrared heat power absorbed by the microbolometer array, and these microbolometric resistance variations can be transformed into voltage signals to form the infrared video image of the target. The microbolometer in the sensor array is normally biased with a pulse voltage bias method to reduce the power dissipation of the whole microbolometric focal plane array, and the resistance variation of the microbolometer under pulse voltage bias is transformed into a certain amount of photo-generated current. The photo-generated current can be integrated onto an integration capacitor to form a voltage signal to be output by the readout integrated circuits in the microbolometric focal plane array. The integration of the photo-generated current needs some time, and the integration capacitor for the microbolometer occupies a little large area of the silicon substrate in the microbolometric focal plane array, where the readout integrated circuits are fabricated. Then, the microbolometric focal plane array is subject to two kinds of bottlenecks, which are the maximum readout speed and the minimum pixel size respectively.

The resistance variation of the microbolometer under pulse current bias can be transformed into a voltage signal to be output by a differential amplifier, which has been introduced by Timothy D. Pope [7], and this kind of high-speed CMOS readout integrated circuit for small-pixel-size microbolometric focal plane array under pulse current bias is proposed in our previously published paper [8]. Because the microbolometric resistance change is directly transformed into voltage, there is no need for the microbolometric

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focal plane array to have some integration time and any of integration capacitors. Without the limit of integration time, the microbolometric focal plane array can support a very high pixel-data readout speed [9]. At the same time, the saving of integration capacitor makes the microbolometric focal plane array to be very suitable for high-space-resolution infrared imaging systems [8,10]. However, it is worth noting that the operating temperature of the microbolometer is not stable during the pulse bias period for the joule power dissipation from the pulse current bias. The responsivity of the microbolometer is closely related to the operating temperature, so it should be carefully investigated in theory for the performance improvement of the microbolometric focal plane array.

R. A. Wood and W. J. Parrish have preliminarily discussed the operating temperature and current responsivity changes for the microbolometer under pulse voltage bias [11,12], but they have not given out the theoretically strict responsivity expression for the microbolometric focal plane array. We have numerically calculated and approximatively provided the responsivity of the microbolometer under pulse voltage bias [13]. The operating temperature expression for the microbolometer under pulse voltage bias is theoretically analyzed and discussed in our previously published paper [14], based on which the microbolometric theoretical output responsivity is strictly deduced and given out in our another previously published paper [15]. But all these mentioned analysis and discussion are not suitable for the responsivity of the microbolometric focal plane array under pulse current bias. In this paper, the microbolometric theoretical responsivity is derived from the physical thermal equilibrium equation of the microbolometer under pulse current bias. The microbolometric responsivity for the microbolometric focal plane array under pulse current bias will be theoretically analyzed and deduced in Section II. The experimental verification of the microbolometric theoretical responsivity will be discussed in Section III, and conclusions will be drawn in Section IV.

2. Microbolometric theoretical responsivity analysis

The microbolometer has normally been constructed in a micro-bridge structure with a thin-film temperature-sensitive material such as vanadium dioxide in the center of the micro-bridge, and two narrow thermally isolated micro-bridge legs are connected to the readout integrated circuits in the silicon substrate of the microbolometric focal plane array [16,17]. If the bias current is I for the microbolometer without infrared absorbed power, the physical thermal balance equation for the microbolometer can be expressed as

$$c\frac{dT}{dt} = I^2R - g(T - T_s), \tag{1}$$

where c is the heat capacity of the microbolometer, g is the thermal conductance of the two micro-bridge legs, R is the resistance of the microbolometer at temperature T, and T_s is the temperature of the silicon substrate. During the current bias period Δt_1 from the pulse current bias start time t_0 to the end time t_1, the microbolometric temperature T can be deduced as

$$T(t) = T_s + \frac{I^2R}{g} + [T_{t=t_{0+}} - (T_s + \frac{I^2R}{g})]e^{-\frac{g}{c}(t-t_0)} \quad (t_0 < t < t_1), \tag{2}$$

where $T_{t=t_{0+}}$ is the initial temperature of the microbolometer at the start time t_{0+}.

In a similar way, the temperature T of the microbolometer without current bias during the period Δt_2 from the time t_1 to the following pulse current bias start time t_2 can be achieved as

$$T(t) = T_s + (T_{t=t_{1+}} - T_s)e^{-\frac{g}{c}(t-t_1)} \quad (t_1 < t < t_2), \tag{3}$$

where $T_{t=t_{1+}}$ is the temperature of the microbolometer at the time t_{1+}. During one whole bias period Δt ($\Delta t = \Delta t_1 + \Delta t_2$), the microbolometric temperature change includes a temperature rise within the pulse current bias time and a subsequent temperature fall within the zero current bias time. Considering that the microbolometric readout response signal is output once every video frame and the video signal output is uninterrupted, the microbolometric temperature changes must contain a consecutive sequence of temperature rising and falling processes, which is illustrated in Fig. 1. For every video frame period (which is equal to Δt), there is a complete pulse current bias power heating and zero current bias power cooling process and the microbolometric final temperature change contains one stable thermal cycle.

When the microbolometer is in the stable thermal cycle state, the initial temperatures of the microbolometer in the heating and cooling cycle can be gotten as

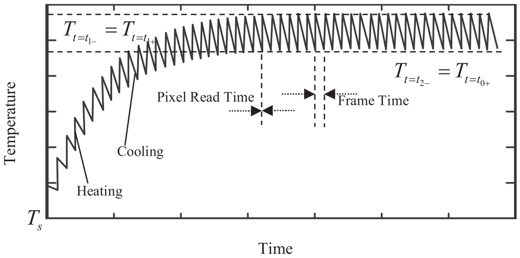

Fig. 1. The microbolometric temperature changing curve.