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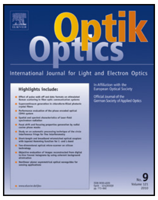

Original research article

Temperature compensation readout integrated circuit for microbolometric focal plane array

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ABSTRACT

Based on the theoretical analysis of microbolometer thermoelectric characteristics and temperature response, a new kind of temperature compensation readout integrated circuit for microbolometric focal plane array is proposed. The proposed readout integrated circuit provides different bias voltages for different microbolometers to control their bias currents and allow the whole microbolometric focal plane array have a wide range of operating ambient temperature. This kind of readout integrated circuit can compensate not only the operating temperature fluctuation but also the thermoelectric-parameter nonuniformity for microbolometer array. Experimental results in our laboratory show that the microbolometric focal plane array on the basis of the proposed readout circuit has well uniform voltage responses of the microbolometers in the focal plane array at different ambient temperatures to the same microbolometric temperature change. The proposed temperature compensation readout integrated circuit is potential for the design of practical low-consumption and high-resolution microbolometric focal plane arrays without thermoelectric coolers.

1. Introduction

With the development of fabricating processes and technologies for microbolometer arrays, microbolometric focal plane arrays have successfully been utilized for many infrared detection, surveillance, and measurement applications [1,2]. When the temperature change of a target is fixed to be 1 K, the corresponding microbolometric temperature change of current microbolometer arrays is normally about 0.01 K [3]. With the consideration that the temperature coefficient of resistance (TCR) of the present-day microbolometer such as vanadium oxide is about 2%, the resistance change rate of the microbolometer with 0.01 K temperature change is only about 0.02%, which is far less than the resistance nonuniformity about 4% of the typical microbolometer array currently [4,5]. Furthermore, the ambient temperature fluctuations of a microbolometer array can deteriorate the infrared response uniformity of the whole microbolometer focal plane array without a large-power-consumption thermoelectric cooler to stabilize the temperature of the microbolometer array. Thus, the design and fabrication of low-consumption and high-resolution microbolometric focal plane array becomes a great challenge for modern infrared image systems.

In order to correct and calibrate the infrared response nonuniformity of a microbolometer array caused by the microbolometer nonuniformity and ambient temperature fluctuation, an external high-speed digital signal processor and a mass data storage device are often adopted with the sacrifice of output dynamic range, which is inevitable to make infrared

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image systems to be complicated and expensive [6,7]. Internal on-chip temperature compensation readout circuit structure is compact and has attracted the interest of many researchers [8]. Conventional on-chip temperature compensation readout integrated circuits provide different bias voltages for different microbolometers to get the same infrared responsivity and need a list of blind elements to improve the output dynamic range for the whole microbolometer array [9], but it can not solve the problem of thermoelectric characteristics inconsistencies between the microbolometer and the blind element. Some on-chip readout integrated circuits with complicated structures can compensate the substrate temperature change and the nonuniformity of microbolometer array at the same time, but they need a lot of high-precision thermosensitive reference elements [10], which is almost impossible for the current micro-electromechanical systems fabricating technology.

In this paper, a new kind of temperature compensation readout integrated circuit structure is introduced. The bias current of this readout structure is controlled by an internal programmable voltage signal and can provide a unique bias to a microbolometer to have a proper infrared responsivity. In addition, an internal programmable reference voltage can follow the microbolometer bias voltage caused by the bias current to improve output dynamic range without any blind or reference element. The effect of ambient temperature drift on the microbolometric infrared responsivity is theoretically analyzed in Section 2. The readout integrated circuit structure and verification of the proposed temperature compensation circuit are introduced in Section 3, and conclusions are drawn in Section 4.

2. Ambient temperature EFFECT analysis

The typical microbolometer such as vanadium oxide is a thermal sensor, and its resistance is temperature dependent to measure the temperature change induced by the absorbed infrared radiation of the microbolometer. Because of that vanadium oxide behaves as semiconductor material, the resistance of the microbolometer can be expressed as

$$R(T) = R_0 e^{\frac{E}{kT}}, \tag{1}$$

where R_0 is a constant relating to semiconductor material, E is the activation energy being equal to half the bandgap of vanadium oxide material, k is Boltzmann constant, and is the microbolometer temperature.

When the operating temperature of the microbolometer is T and its temperature change is dT caused by a certain amount of infrared irradiation power, the microbolometric resistance change from Eq. (1) is

$$dR = -\frac{R_0 E}{kT^2} e^{\frac{E}{kT}} dT. \tag{2}$$

The operating temperature T can be derived from the microbolometer thermal structure and bias method [11]. For the microbolometer with micro-bridge structure under a constant current bias, its operating temperature T is

$$T = T_a + \frac{I^2 R(T)}{g}, \tag{3}$$

where T_a is the substrate ambient temperature, I is the bias current, and g is the thermal conductance of micro-bridge construction. From Eqs. (1) and (3), the operating temperature T in Eq. (2) can be obtained through numerical calculation.

From the analysis above, it can be concluded that the microbolometer resistance changes even produced by the same temperature increment are obviously different at different ambient temperatures. Furthermore, the constant R_0 of one microbolometer at a certain temperature is often different from that of another at the same temperature due to the restriction of fabricating technology for microbolometer array. Generally, each microbolometer in an array has its unique resistance-temperature responsivity resulted from the microbolometer resistance nonuniformity of the whole array and ambient temperature drifts can aggravate the resistance-temperature response uniformity of the microbolometer array.

3. Temperature compensation circuit

The proposed temperature compensation readout integrated circuit structure is shown In Fig. 1. The bias current for each microbolometer R is controlled by a voltage signal, which is transformed through a DAC (Digital to Analog Converter) from the bias data stored in an external memory. The reference voltage to the differential amplifier is utilized to subtract the microbolometric quiescent bias voltage induced by the bias current. The bias data in the external memory is obtained by an external data processor, and the reference voltage data in the internal M × N word memory is achieved through the voltage sampling switch. The operational principle of the readout circuit structure can be explained as following. In the normal working condition of the readout circuit, the microbolometric infrared response voltage signals transformed from the resistance changes of these microbolometers in Fig. 1 are sampled on the capacitors of the differential amplifiers row-by-row through the M-row selecting switches and output column-by-column through the N-column selecting switches. During the calibration data acquisition period of the readout circuit, the microbolometric output signals response to the infrared irradiation of uniform targets are collected by the external data processor to get the bias data for writing in the external memory. During the same period, the voltage sampling switch is turned on to get the reference voltage data to be stored in the internal M × N word memory. The calibration and reference voltage data acquisition process can be referred to our previously published paper [4].