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SOME PROBLEMS OF THERMOELECTRIC THERMAL STABILIZATION OF MICROBOLOMETRIC ARRAYS OF INFRARED RANGES

Technical features of devices based on uncooled microbolometric arrays of infrared ranges are considered. A thermopile is shown to be the best tool for precision thermal stabilization of microbolometric arrays. Construction criteria for selection of a thermopile for devices with such architecture are defined.

Key words: microbolometric array, thermopile, thermostabilization.

Introduction

Analysis of modern high-technology branches of science and engineering shows that they have been really implemented in many kinds of new enginery. They primarily include developments of systems of deep-space thermal imaging of ballistic missile launches, thermal imaging systems of tank and aircraft fire control, high-precision missile and artillery weapons with laser guidance, antiballistic missile systems, multispectral anti-aircraft complexes, optic and fiber-optic data-transmission systems, developments of laser range finding devices, especially at eye-safe wavelength, etc. The role of optics and infrared equipment in such weapons is fundamental, since precisely optico-electronic systems determine the operational range, energy consumption, weight and dimensions of defence complexes. In some instances the task simply cannot be solved without the use of devices recording the intrinsic thermal radiation of a real target, for instance, with the availability of numerous decoys or radio interferences making radiolocation inefficient. Therefore, of particular importance are fully passive infrared systems that do not radiate and, hence, cannot be detected by means of radioelectronic intelligence and suppression [1].

Infrared radiation photodetectors are the key elements of almost any optico-electronic system. In the majority of cases the efficient operation of these devices requires cooling of their semiconductor photosensitive elements, assuring the advantage of optical generation of charge carriers over heat spreaders [2]. In so doing, one of the most in-demand cooling methods for the above purposes is thermoelectricity enabling to achieve the necessary detectability values of photodetector mainly in the medium-range (3-5 μm) spectral region. At the same time, it should be noted that further development of solid-state photoelectronics engineering in recent years has been largely dependent on mass introduction into equipment of microbolometric arrays (MBA) for infrared range of 8-14 μm [3]. The operating principle of MBA is as follows: optical radiation coming to MBA is absorbed and heats sensitive element that has sufficiently high temperature coefficient of resistance. Resistance change due to heating is converted into voltage, i.e. to recorded signal.

A distinguishing design feature of these devices is, as a rule, the absence of any cooling system and, therefore, thermal imaging module has lower energy consumption, dimensions and mass.

Production of MBA based on vanadium or silicon oxide is considerably cheaper compared to cooled photodetectors. At the same time, using MBA necessitates account of certain factors that predetermines the presence in them of a precision MBA temperature controller based on a single-stage thermopile. However, due to lack of scientific and technical publications on this subject matter there is certain information gap with regard to validity and necessity of using thermopile for the above purpose, as well as the specificity of devices with their application. It is precisely these aspects that the present paper is concerned with.

Technical features of devices

Structurally, MBA are a set of microbridges. Each of them rests on a silicon plate by means of two dielectric supports with a minimal thermal conductivity. Such MBA arrangement assures its higher thermal resistance relative to the substrate. For the same purpose, MBA are mounted in evacuated packages. This prevents leakage from MBA of stored thermal energy of absorbed IR-radiation [3]. Strictly speaking, to be operated, MBA need not be cooled relative to ambient temperature. At the same time, rather rigid requirements are imposed on the stability of MBA operating temperature T_s. These requirements are governed by the optics of a device where it is used, the MBA area, its temperature coefficient of resistance and the value of thermal bonding to substrate, as well as by other factors [4].

Calculations performed by the author show that for MBA based on vanadium film to record a change in observed object temperature (ΔT_{OB}) by $1.5\cdot10^{-1}$ K is only possible with the accuracy of its thermal stabilization (ΔT_{B}) on the level of $\pm\,5\cdot10^{-3}$ K.

The accuracy of temperature control in the range of ± 5–10 mK is governed by the fact that the increment of bolometer temperature ΔT_{B} with a change in object temperature ΔT_{OB} corresponds to expression:

$$\Delta T_{\mathrm{B}}(\Delta T_{\mathrm{OB}}) \approx R_T K_{\Delta\lambda}\mu_{\Delta\lambda}\Delta T_{\mathrm{OB}} A_{\mathrm{B}}(\partial M_{\Delta\lambda}/\partial T_{\mathrm{OB}})/4F_{\#}^2,$$

where R_T is bolometer thermal resistance, K/W;

$K_{\Delta\lambda}$ is effective value of microbolometer radiation absorptivity in the spectral range of $\Delta\lambda$;

$\mu_{\Delta\lambda}$ is effective value of lens transmission factor in the same range;

A_{B} is microbolometer area, cm^2;

$M_{\Delta\lambda}$ is power density of object radiation in the range of wavelength $\Delta\lambda$, W/cm^2;

$F_{\#}$ is inverse aperture of the objective.

In the case in hand the values appearing in the expression have the following guide values: $R_T \le 1\cdot10^7$ K/W; $K_{\Delta\lambda} \approx 0.7$; $\mu_{\Delta\lambda} \approx 1$; $A_{\mathrm{B}} \approx 3.5\cdot10^{-5}$ cm^2; $\partial M_{\Delta\lambda}/\partial T_{\mathrm{OB}} \approx 2.6\cdot10^{-4}$ W·cm^{-2}·K^{-1} ($\Delta\lambda$ = 8–14 μm); $F_{\#} = 0.7$.

Then, at $\Delta T_{\mathrm{OB}} = 0.15$ K the accuracy of thermal stabilization $\Delta T_{\mathrm{B}}\,(0.15) \le 5\cdot10^{-3}$ K.

Thermoelectric thermal stabilization of MBA

Generally speaking, thermal stabilization devices are divided into passive and active. Passive devices do not comprise any sources of heat or cold, hence the impossibility of high accuracy of thermal stabilization over a wide range of ambient temperature T_0.

On the contrary, active devices comprise the sources of heat or cold (separately or together). In so doing, depending on the level of T_s active thermal stabilization with change in temperature T_0 from $T_0^{\min}$ to $T_0^{\max}$ can be of three types.

Low-temperature thermal stabilization, when $T_s<T_0^{\min}$, is characterized by the presence of surplus heat and is of limited use in semiconductor instrument making.

Normal thermal stabilization, when $T_0^{\min} < T_s < T_0^{\max}$, is distinctive in that at different times one needs either to deliver heat or remove it. This method is most widely used at $T_s = 283$—298 K.

High-temperature thermal stabilization when $T_s > T_0^{\max}$ requires constant delivery of heat to the desired object.

Due to the fact that for MBA $T_s = 283$—298 K, only normal thermal stabilization is discussed hereinafter. With regard to this factor it must be admitted that thermopile is the best tool for precision thermal stabilization of MBA. Being simultaneously possible source of heat and cold, thermopile offers a variety of technical advantages, including small dimensions, mass, energy consumption and response time, design simplicity, high reliability, noise-free operation, absence of microphonic effect, independence of attitude in space, etc. The above complex of distinctions for thermopile is quite trivial, making it most preferable for the attainment of the above goal [5].

Active normal thermal stabilization by means of a thermopile can be implemented by one of the following methods:

- purely thermoelectric, when heating and cooling are assured by the respective polarity of thermopile supply voltage;
- thermoelectric cooling and electric heating;
- thermoelectric cooling or heating with additional electric heating.

The second method is used for thermal stabilization of objects in a wide temperature range with the value of T_s close but lower than T_0. Energetically it is inferior to the first method and structurally it is more complicated.

The third method is a combination of the above. It is intended for thermal stabilization under conditions typical of the second method with a forced heating mode. Energetically, as compared to other methods, it is less beneficial, and structurally it is similar to the previous one.

Among the methods of active normal thermal stabilization, with common requirements to it, purely thermoelectric method is optimal. This thesis is also valid in the case of MBA devices.

Thermopile selection in such and similar devices is governed both by the given level MBA thermal stabilization and by its geometric dimensions. At the same time, in such devices, as a rule, it is necessary to assure in addition high degree of thermal stabilization uniformity along MBA area ($\leq 2\cdot10^{-2}$ K). The same rigid requirement dictates, accordingly, the design and general architecture of thermopile. It is apparent that thermopile should comprise an increased amount of thermoelements with a relatively high packing, i.e. with minimal distances between them. In so doing, on the working site of thermopile a large amount of closely spaced discrete sources of cold or heat is arranged, which objectively contributes to implementation of technical challenge set. Further leveling of the temperature field provides for manufacture of thermopile working site of high thermal conductivity ceramic material, for instance, beryllium oxide or aluminum nitride. In certain cases for the same purpose use is made of a copper plate mounted on thermopile working site.

The necessary accuracy of MBA temperature control is realized by means of appropriate element base and hardware, including temperature sensor. In [4], the results of testing the elaborated system of MBA thermal stabilization based on a single-stage thermopile that provided for selection of T_s in the range of 283–298 K to an accuracy of $\pm 2.5\cdot10^{-3}$ K at $T_0 = 288$–303 K. This data is in good agreement with the above formulated technical requirements to MBA thermal stabilization systems.

Conclusions

The present paper is not intended to be a comprehensive and detailed presentation of all the problems with which the developers of infrared engineering are faced when creating MBA thermal stabilization systems. The author has just indicated some key aspects to be taken into account without fail and plans to continue publications on this subject matter.

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