Infrared Physics & Technology 68 (2015) 167–172

Contents lists available at ScienceDirect

Infrared Physics & Technology

journal homepage: www.elsevier.com/locate/infrared

A two-section false cap for fuze thermophotovoltaic power supply

Chunhua Yu [a,*], Xinglin Qi [a], Min Gao [b]

[a] Department of Ammunition Engineering, Mechanical Engineering College, 97 West Heping Rd., Xinhua District, Shijiazhuang, Hebei Province 050003, PR China
[b] Department of Missile Engineering, Mechanical Engineering College, 97 West Heping Rd., Xinhua District, Shijiazhuang, Hebei Province 050003, PR China

HIGHLIGHTS

- We propose a two-section false cap for fuze TPV power supply.
- Higher and more uniform temperature in the two-section false cap.
- More valid radiation for TPV cell.
- The generation power and efficiency of this power supply is much higher.

ARTICLE INFO

Article history:
Received 28 September 2014
Available online 12 December 2014

Keywords:
Two-section false cap
Thermophotovoltaic
Fuze
Power supply

ABSTRACT

The fuze thermophotovoltaic (TPV) power supply converts the thermal radiation of fuze's false cap into electric power directly and the generated power increases with the increasing of false cap's temperature. Thus, in order to increase the temperature of the false cap, a two-section false cap consisting of two materials of different thermal conductivity is proposed. The results of numerical simulation indicate that compared with common false cap made of single material, the two-section false cap enjoys higher and more uniformly distributed temperature in the hemispherical nose's inner surface, and thus its radiant power is greatly enhanced. Moreover, it is also verified by the experimental results that both the generation power and efficiency of fuze TPV power supply with two-section false cap are much higher than those of common false cap. Therefore, the two-section false cap contributes greatly to improving the performance of fuze TPV power supply and thus it can be applied to fuze power supply in the future.

1. Introduction

The TPV (Thermophotovoltaic) generation technology, which converts thermal radiation to electric power directly, was first proposed by an American scholar named Kolm [1]. In 1970s and 1980s, U.S. military had once made a study of applying TPV technology to field generator [2] and underwater unmanned vehicle generator [3]. However, the TPV technology had little practical value then due to the extremely low efficiency of photoelectric conversion. It is not until the mid-1990s when a kind of TPV cell made of GaSb was developed that the TPV technology gained significant development and became feasible in practice. In 2008, the application of TPV technology to ammunition was first proposed by ARDEC (Armament Research, Development and Engineering Center) of U.S. Army. They conducted many experiments on it, through which TRL6 (Technology Readiness Level 6) was achieved [4]. In 2009, Amabile et al. [5] in ARDEC proposed a hybrid power system for fuze of ammunition, in which the TPV technology was utilized. However, both the generation power and efficiency of the TPV cell in this system were low due to low temperature of the false cap. In order to promote the temperature of false cap so that the generation power and efficiency can reach a higher level, a two-section false cap for fuze TPV power supply is proposed.

2. Structure of fuze TPV power supply

The half-section view of fuze TPV power supply is shown in Fig. 1.

Here, the component "1" refers to the false cap of fuze located at the head of ammunition. When ammunition travels at supersonic speed, the temperature of false cap will rise rapidly due to the intense aerodynamic heating effect [6]. A steady temperature field will be formed ultimately, in which the temperature of the false cap's stagnation point is higher than that of any other points on outer surface or inner surface.

* Corresponding author. Tel.: +86 18266120553, +86 0311 87994399; fax: +86 0311 87992016.
E-mail address: huazai19870224@163.com (C. Yu).

http://dx.doi.org/10.1016/j.infrared.2014.12.008
1350-4495/

Furthermore, the component "3" is a TPV cell, a semi-conductor PN junction in essence. The TPV cell can absorb photons (or thermal radiation) emitted by the false cap's inner surface and generate free charges. With the built-in electric field of PN junction, these charges move to the two electrodes of the cell and are collected by electrodes, thus forming an electromotive force between the two electrodes to drive external load. The minimum energy of photon that the TPV cell can absorb and utilize is called bandgap [7].

And the component "2" is a filter, which can transmit some bands of radiant spectrum through the interference of light, whereas other bands will be reflected. In the fuze TPV power supply, the filter stops photons whose energy are lower than the bandgap from reaching the TPV cell, otherwise these photons will heat the TPV cell and cause decrease of generation efficiency.

Moreover, the component "4" is a heat sink. In the generation process, the temperature of TPV cell rise gradually, which decreases the generation power and efficiency, or even results in irreversible damage [7]. The heat sink can slow the temperature rise by its thermal capacity.

3. Principle of two-section false cap

According to Stephan–Boltzmann Law and Wiens Displacement Law [8], with the temperature rising, thermal radiation of the false cap increases quickly, and radiant spectrum moves towards the shortwave direction. In other words, the higher the false cap's temperature is, the more effective radiation is available for TPV cell, and thus the higher power can be generated by cell. Therefore, the generation power of fuze TPV power supply can be remarkably improved by increasing the temperature of the false cap, especially the inner surface temperature of false cap's head.

Fig. 2 shows the simulation results of the steady-state temperature field of false cap, whose material is Silicon Carbon (SiC), cavity is filled with air, hemispherical nose's radius is 10 mm, conical tail's half conical angel is 10°, and flight speed is Mach 5. According to Fourier Law [8], heat always transfers in negative direction of temperature gradient, that is, the direction of heat transfer is erect to isotherms. Therefore, accordingly, the heat absorbed by the hemispherical nose's outer surface will be transferred to the conical tail and eventually dissipate through the conical tail's outer surface in the steady-state. Fig. 3 shows the distribution of net heat flux of false cap's outer surface in the steady-state. The *x*-axis represents the horizontal distance between the point of false cap's outer surface and the stagnation point and the *y*-axis represents the net heat flux of the point, that is, the algebraic sum of aerodynamic heat flux absorbed and radiant heat flux emitted.

There are two paths along which the heat is transferred from the hemispherical nose to the conical tail. One is through the body of false cap, and the other is through the air inside the false cap. Supposing that the contact interface of hemispherical nose and conical tail is adiabatic, the temperature of hemispherical nose will continue to rise at the steady-state because the first path of heat transfer is blocked. If the conical tail is made of a material of low thermal conductivity, heat transferred through the second path will be suppressed, too, which also leads to the increase in temperature of hemispherical nose.

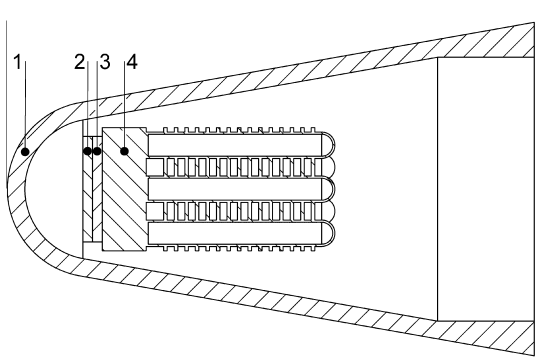

Fig. 1. Structure of fuze TPV power supply.

Based on the above analyses, a two-section false cap is proposed, which is composed of two different materials bonded together by a high-temperature adhesive, as shown in Fig. 4. In the two-section false cap, the hemispherical nose marked with "1" in Fig. 4 is made of ceramic material SiC, whose high thermal conductivity makes its temperature distribution more uniform, and whose high emissivity makes it a good emitter for fuze TPV power supply. The conical tail marked with "3" in Fig. 4 is made of ceramic material Zirconium Oxide (ZrO_2), whose low thermal conductivity and low emissivity can not only contribute to the rise in temperature of hemispherical nose, but lower the invalid radiation towards the TPV cell inside the false cap. Thus, it can slow the temperature rise of the TPV cell. The high-temperature adhesive marked with "2" in Fig. 4 plays the role of connector and heat insulator.

4. Numerical simulation

In order to verify the effect of two-section false cap theoretically, a simulation of the temperature fields of a two-section false cap and a common false cap was conducted in the software *FLUENT*.

4.1. Simulation settings

4.1.1. Structure parameters

The two-section false cap and the common one are of the same shape and size, which means both of them are made up of a hemispherical nose whose radius is 10 mm and a conical tail whose half conical angel is 10°. The two false caps are both 2 mm thick and 90 mm long.

4.1.2. Material parameters

In the two-section false cap, the material of hemispherical nose and conical tail are SiC and ZrO_2 respectively. The high-temperature adhesive is made of sodium water glass. The common false cap is composed exclusively of SiC. The thermal physical characteristics of those above mentioned materials [9–11] are shown in Table 1.

4.1.3. Flight parameters

The flying height, flying speed and angle of attack are set as 500 m, Mach 5 and 0° respectively, without consideration of gravity.

4.2. Simulation results

The four pictures in Fig. 5 show the simulation results of the inner surface temperature of the two false caps when elapsed time of aerodynamic heating is 1 s, 10 s, 100 s and in the steady-state respectively. In the figure, the red[1] line and the blue line refer to the two-section false cap and the common false cap respectively. It is very obvious that the temperature of the two-section false cap's hemispherical nose is much higher and distributes more uniformly than that of the common false cap. On the contrary, the temperature

[1] For interpretation of color in Figs. 4 and 5, the reader is referred to the web version of this article.