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Investigation of the Peltier Cooling Effect Using Low Cost n-Cu_2O and p-Cu_2S Semiconductors

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ABSTRACT

Thermoelectricity is a branch of Physics which describes the conversion of thermal energy into electrical energy (the Seebeck effect) and vice versa (the Peltier effect). Since early days, tellurium-based alloys and semiconductors have been used for Peltier applications. In this study, electrodeposited n-Cu_2O and p-Cu_2S semiconductors were used as low cost materials to study the Peltier effect. These semiconductors were stacked electrically in series while thermally in parallel to fabricate a single-stage module or multi-stage modules. When applying low voltage DC power, heat was generated and transferred through the module. There was an observed temperature gradient of 4 $°C \cdot mm^{-1}$ across the five-stage module at 4.25 V of DC power. This effect can be improved by increasing the input power. Although the module exhibits the presence of both the Peltier and Joule effects, the Peltier effect dominates above an applied voltage of 4.0 V. Results reveal that there is a possibility of fabricating a Peltier device using low cost copper-based semiconductor materials.

1. INTRODUCTION

The phenomenon of thermoelectricity is mainly based on the Seebeck and Peltier effects which describes the conversion of thermal energy into electrical energy and vice versa respectively. In early 19th century, French physicist, Jean Peltier (1785-1845), discovered the generation of a temperature gradient across two dissimilar metal junctions kept in a potential difference and was later known as the Peltier effect [1]. This is a reversible process. In 1954, H. J. Goldsmid reported that n-type and p-type semiconductors show better the Peltier effect compared to dissimilar metal junctions and Bi-Te alloys worked better to serve the purpose [2]. Tellurium-based alloys and semiconductors have been widely used later in Peltier applications [3, 4]. As tellurium is a rear earth material, it is a great advantage to find inexpensive alternative materials. Preliminary study was carried out to observe the effectiveness of the Peltier effect using low cost materials of n-type cuprous oxide (Cu_2O) and p-type cuprous sulphide (Cu_2S) semiconductors [5]. In the present work, possibility of fabricating a Peltier device has been investigated using n-Cu_2O and p-Cu_2S semiconductors.

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2. EXPERIMENTAL

Two identically separated n-Cu_2O thin films were potentiostatically electrodeposited on a copper substrate in an acetate bath [6]. Dimensions of the substrate are 12×28×0.07 mm^3. As shown in Fig. 1, one half of each Cu_2O thin film was then sulphided by dipping in an aqueous sodium sulphide solution in order to grow p-Cu_2S.

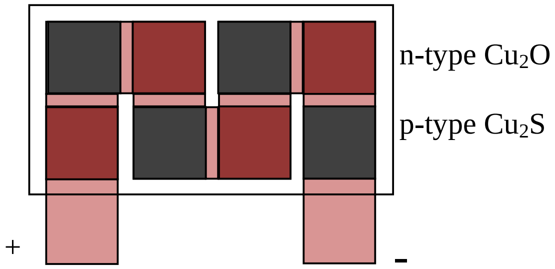

Fig. 1: Top view of the single-stage module

These films were arranged on a mica sheet in such a way that two of the same type of semiconductors was placed on each other electrically in series as shown in Fig. 1. A single-stage module was subsequently sandwiched by two mica sheets to make the module thermally in parallel. As the effect was minimal for the single-stage module, several of these modules were assembled electrically in series to fabricate a multi-stage module. In this study, a five-stage module was tested by using mechanical press contact technique. I-V characteristic of the device was obtained in order to understand the internal behavior. Temperatures of the top and bottom layers of the module were measured by varying the applied voltage.

3. RESULTS AND DISCUSSION

Two separated, similar areas of n-Cu_2O thin films were potentiostatically electrodeposited on a Cu substrate in an acetate bath for 60 min. The thickness of the electrodeposited Cu_2O thin films was uniform and around 1.3 μm and it was calculated by monitoring the current passing through the working and counter electrodes during the electrodeposition process. The growth of p-Cu_2S thin films was carried out by sulphiding one half of each Cu_2O thin film in an aqueous sodium sulphide solution. Pinkish red colour Cu_2O changed into black colour after sulphidation, indicating the conversion of n-Cu_2O into p-Cu_2S.

In order to enhance the thickness and quality of the semiconductor layers, two films of n-type or p-type were placed on top of each other. These films were connected electrically in series on a mica sheet to make one layer of samples. These layers were sandwiched between mica sheets in order to fabricate the single-stage modules. For this study, five single-stage modules were stacked thermally in parallel with each other to fabricate a five-stage module. The thickness of the five-stage module is about 0.6 mm. Power was applied to the module using the mechanical press-contact technique. Although this was not a real good way to obtain proper contacts, there was no better method to try out with the available resources. Temperatures of the top and bottom layers of the module were measured by placing a cooling fan just outside of the heat liberating side of the module to remove the accumulated heat and thereby to prevent excess heating of the device.

Internal behavior of the five-stage module was examined by monitoring the current through the module with the applied DC voltage and the observed variation is as shown in Fig. 2. It shows a demarcation region around 3.5 V. The variation of the current when the voltage is below and above 3.5 V indicates that two significant effects take place within the module while increasing the applied voltage.

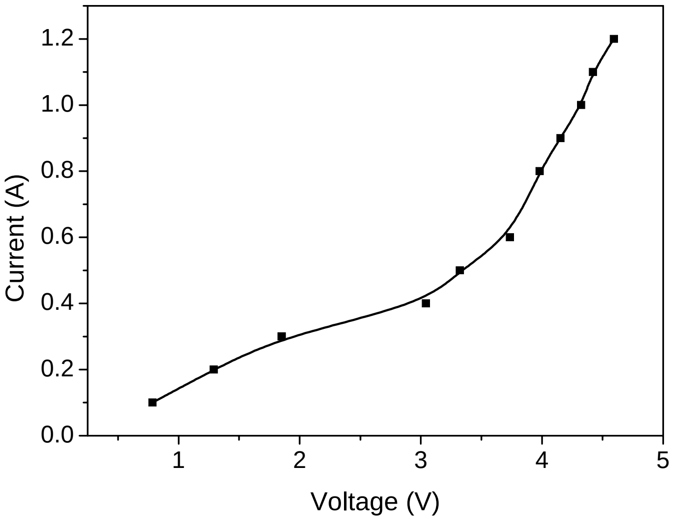

Fig. 2: I-V characteristics for the five-stage module

The temperature variations of cold and hot sides of the module with the applied voltage are illustrated in Fig. 3. It shows that three regions of temperature variations exist for both sides of the module as in the case of voltage regions of I-V characteristics. This suggests that two physical processes occur simultaneously inside the module while applying the input power. Major physical processes of thermoelectric devices are the Joule effect and the Peltier effect. The linear variations within the voltage region below 3.0 V in Fig. 3 indicate that the Peltier effect is inferior compared to the Joule effect. Beyond the region of 4 V, the variation seems to be nonlinear and it suggests that the Peltier effect is more significant. The transition region shows both effects. However, it indicates that, within this region, the Joule effect is overcome by the Peltier effect.

In Fig. 3 and also in Fig. 5, it is clearly seen that the temperature difference of cold and hot sides increases with the applied voltage across the module. The increments of temperature difference are a proof of the existence of the Peltier effect. For example, a temperature gradient of 1 $°\mathrm{C{\cdot}mm^{-1}}$ at 3.5 V or 4 $°\mathrm{C{\cdot}mm^{-1}}$ at 4.25 V of DC voltage across the module can be observed. This phenomenon would not happen unless the Peltier effect was present across the module of copper-based semiconductors.

The temperature variations of cold and hot sides of the module are given in Fig. 4 for the case of accumulating heat inside the module.

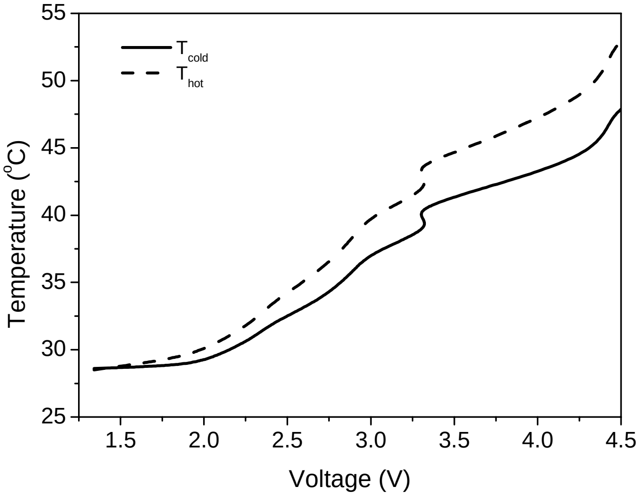

Fig. 3: The temperature variations of the cold and hot sides of the module with the applied voltage, when a cooling fan is used.

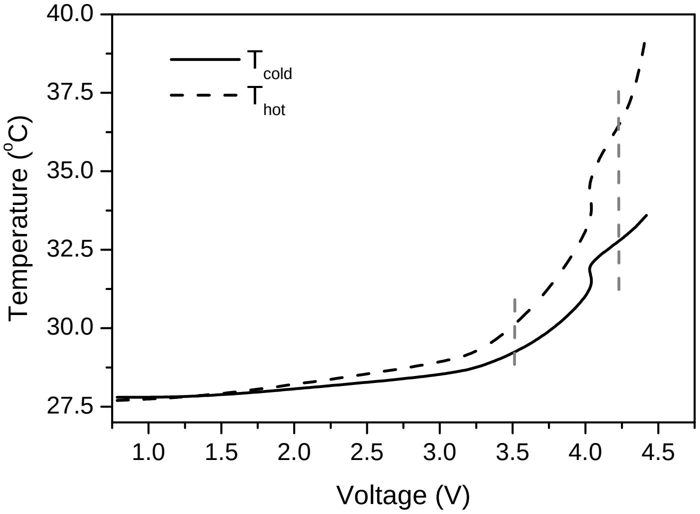

Fig. 4: The temperature variations of the cold and hot sides of the module with the applied voltage, when a cooling fan is not used.

Even though a temperature difference is maintained across the module when compared with Fig. 3, a noticeable temperature rise from both sides of the module can be observed. Without a cooling fan, heat would be trapped inside the module and this will result in an increase in the temperature of both sides. This may also cause damage to the device due to excess heat.

Fig. 5 shows how the temperature difference varies with the applied potential for the two cases, with and without a cooling fan, when monitoring the accumulated heat inside module.

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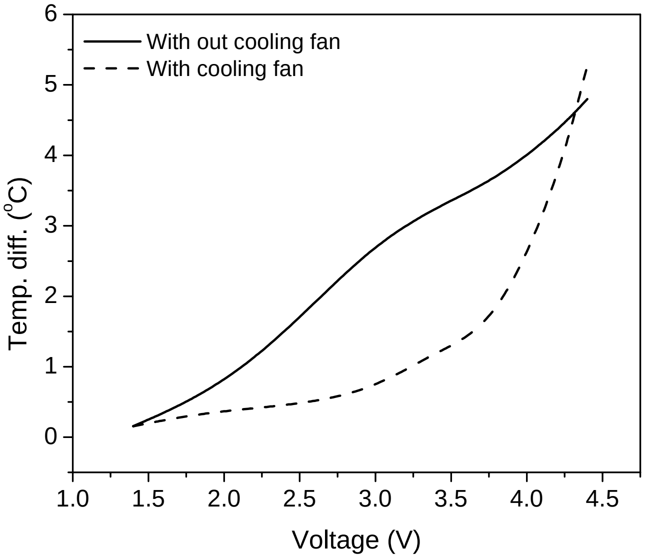

Fig. 5: The variations of the temperature difference with the applied voltage of the module, when a cooling fan is used/not used.

Fig. 5 illustrates that the temperature difference is linear when heat is accumulated inside the module. This fact indicates that the temperature rises due to Joule effect while weakening the Peltier effect. The Peltier effect was clearly visible when applying a cooling source to the hot side of the module minimizing the impact of the unavoidable Joule effect.

4. CONCLUSION

The findings of this research work proved that n-Cu_2O and p-Cu_2S semiconductors could be used to study the Peltier effect even though both the Peltier and Joule effects present within the thermoelectric module. The temperature gradient can be observed as rising while increasing the applied voltage. This kind of temperature variation indicates that the Peltier effect is the dominant process in the higher voltage region. In conclusion, low cost Peltier modules can be fabricated using n-Cu_2O and p-Cu_2S semiconductor thin films.

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