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Micro-thermoelectric generators based on through glass pillars with high output voltage enabled by large temperature difference

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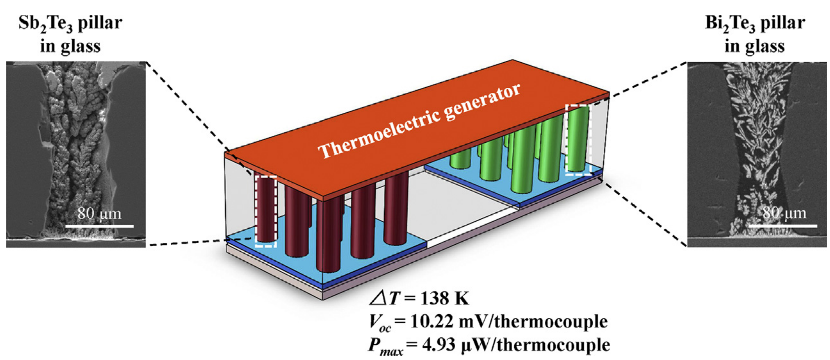
HIGHLIGHTS

- 200 μm-length thermoelectric pillars are electrodeposited.
- Glass templates with through holes are used to support thermoelectric pillars.
- Micro-thermoelectric generators based on through glass pillars are fabricated.
- Each thermocouple delivers an open-circuit voltage of 10.22 mV.
- A large temperature difference of 138 K is established.

GRAPHICAL ABSTRACT



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ABSTRACT

Micro-thermoelectric generators can convert low-grade waste heat to electrical power and have potential applications in wearable electronics, wireless sensors, medical devices and so on. It is challenging to increase the output voltage and power of the cross-plane micro-thermoelectric generators, because their thermoelectric legs are short and a large temperature difference cannot be established on the devices. In this work, we fabricate a micro-thermoelectric generator based on Bi_2Te_3 and Sb_2Te_3 through glass pillars with a length of 200 μm. These thermoelectric pillars are electrodeposited in the through holes of glass templates, and the glass templates are used to support the pillars. A temperature difference of 138 K is successfully established for the thermoelectric generator with 4 thermocouples. The maximum output voltage of the device is 40.89 mV under a temperature difference of 138 K; each thermocouple delivers a voltage of 10.22 mV. The maximum output power of the device is 19.72 μW. Both the temperature difference and the output voltage per thermocouple are the largest for the cross-plane micro-thermoelectric generators based on thin-film deposition technologies in the literature. In addition, finite element modeling is carried out to study the effects of the length and coverage rate of the

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thermoelectric pillars on the performance of the thermoelectric generators. Both the experimental and simulation data show that it is an effective way to enhance the temperature difference and output voltage of cross-plane micro-thermoelectric generators using through glass pillars.

1. Introduction

With the rapid development of human society, global energy consumption is steadily increasing and there is a strong demand to raise the efficiency of energy utilization. One effective approach for improving energy efficiency is to recover waste energy. About 20–50% of energy consumed in manufacturing processes ultimately results in waste heat through heat conduction, convection, and radiation; therefore, waste heat recovery is critical for increasing the overall efficiency of energy utilization [1–3]. Among various technologies for waste heat recovery, thermoelectric power generation is attracting great research interest because thermoelectric generators (TEGs) can directly convert waste heat to electricity [4–8]. TEGs have many advantages such as high reliability, no mechanical movement, no noise, and fast response. Thus they have been widely used for waste heat recovery in natural or industrial heat sources [9,10], automobiles [11–13], wearable and flexible electronics [14–17], interplanetary vehicles [18], medical devices [19] and so on.

TEGs can be divided into two categories according to size: bulk-type TEGs and micro-TEGs. Bulk-type TEGs typically have a height of more than 1 mm and are usually used to generate power under a temperature difference ΔT of 300–600 K [5,20–22]; therefore, medium-grade

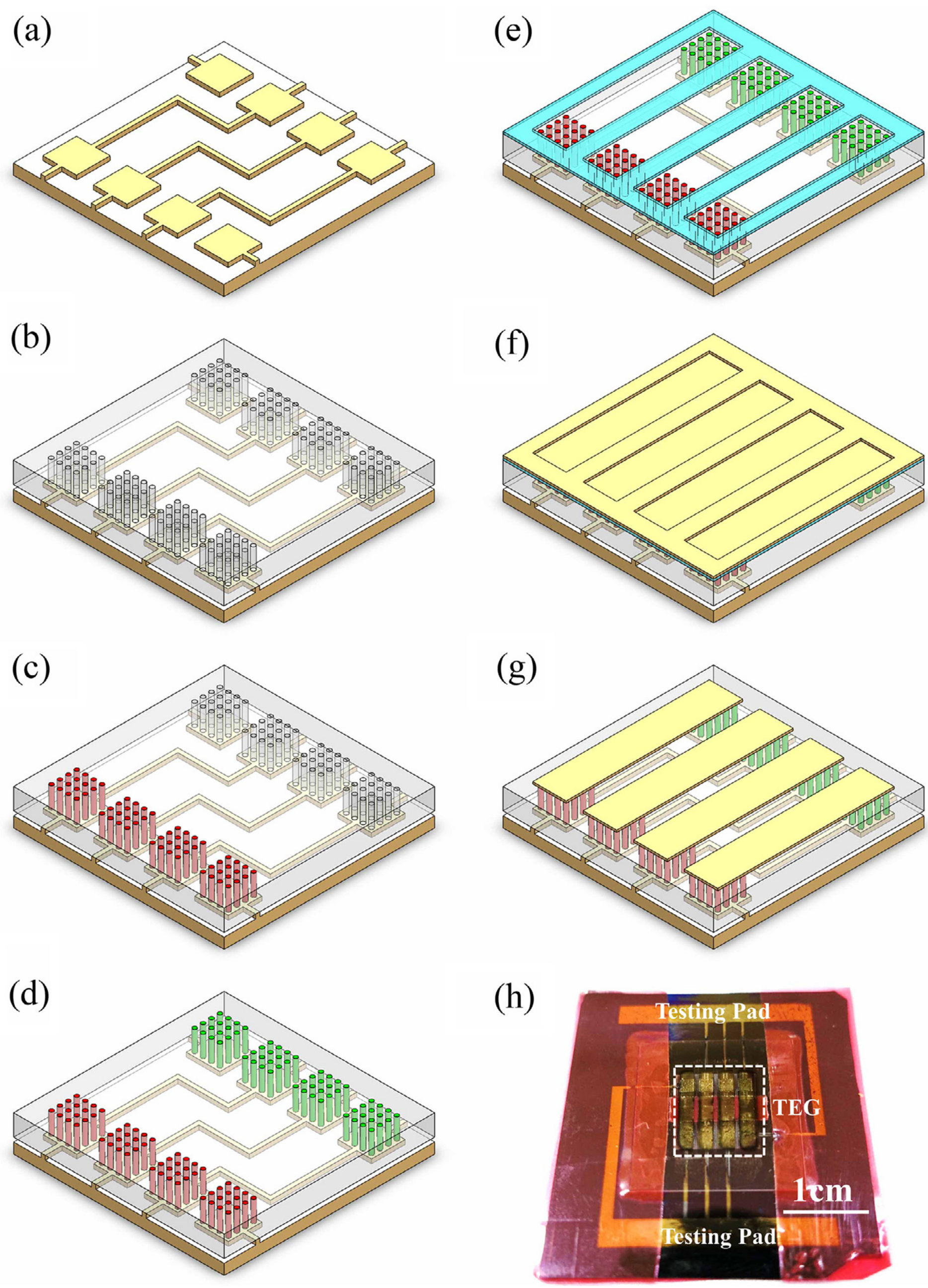

Fig. 1. Fabrication processes of micro-TEGs.