FABRICATION AND PERFORMANCE TEST OF A POLY-SI MICRO THERMOELECTRIC GENERATOR

Hyunse Kim*, Yanglae Lee, Ook Joong Kim, Kong Hoon Lee and Pil Woo Heo
Energy Plant Research Division, Korea Institute of Machinery and Materials, Republic of Korea
*Presenting Author: hkim@kimm.re.kr

Abstract: Micro thermoelectric generators (μ-TEGs) have been developed for energy harvesting devices. So several kinds of μ-TEGs, which are focusing on having compact and portable power generating structures have been proposed for mobile applications. Furthermore, the efforts to raise the energy conversion efficiency and to lower the fabrication costs have been done on the related researches. In this paper, semiconductor process compatible polycrystalline silicon (poly-Si) μ-TEG having low production cost and higher performance efficiency was developed. The structure of the μ-TEG is described with working principles. The fabrication processes are explained with detailed deposition or etching conditions. The transport properties of Seebeck coefficient and electrical conductivity were measured. And power factors were obtained as 527 $\mu Wm^{-1}K^{-2}$ and 1160 $\mu Wm^{-1}K^{-2}$, for the P-type and the N-type poly-Si films, respectively. Additionally, the figure of merit was measured using an experimental setup as 0.873. As a conclusion, the developed μ-TEG is likely to be an energy source from the wasted heat and expected to raise the energy efficiency.

Keywords: Micro thermoelectric generators (μ-TEG); Seebeck effect; Polycrystalline silicon (poly-Si) films

INTRODUCTION

Recently, micro thermoelectric generators (μ-TEGs) are being widely developed for energy harvesting devices and they are also considered to be a portable and safe solution for mobile applications [1]. The need to raise the energy conversion efficiency and to simplify the fabrication processes is a major challenge to the researchers. Several TEGs using silicon (Si) based material or bismuth telluride based compounds as thermoelectric materials have been developed [2-6]. Especially, Si based materials have been used for micro fabrication approach and they have several different compound combinations such as Si, polycrystalline silicon (poly-Si), silicon-germanium (SiGe) and polycrystalline silicon-germanium (poly-SiGe), which have thermoelectric properties. But fabrication processes of previous TEGs involve many steps, so it is hard to realize a mass-production for lowering manufacturing costs.

In this work, a semiconductor process compatible μ-TEG having low production cost and higher performance efficiency was proposed. The structure of the μ-TEG is described with working principles. The fabrication processes are explained with detailed deposition or etching conditions. The transport properties such as Seebeck coefficient and electrical conductivity, are measured and analyzed. Finally, figure of merit is measured and power generation performance of the device is discussed.

μ-TEG STRUCTURE AND WORKING PRINCIPLE

The fabricated μ-TEG using complementary metal oxide semiconductor (CMOS) process is shown in Fig. 1. The device size is 14 × 17 mm and the main area occupied by the thermoelectric columns is 10 × 10 mm. This μ-TEG is composed of 36 thermoelectric columns, and dimensions of each column are 1000 × 1000 × 0.3 μm (width × depth × height), respectively, as illustrated in Fig. 2. Thermoelectric material of the P-type and N-type columns in the μ-TEG was Poly-Si.

Top sides of P-type and N-type columns are electrically connected in serial, and bottom sides of each couple are also connected with metal electrodes. For an electrical isolation from the Si substrate, an oxide layer is deposited between the bottom electrodes and the substrate. Both ends of the metal electrodes are bonded with wires and they can be connected to an electrical system which needs power for working.

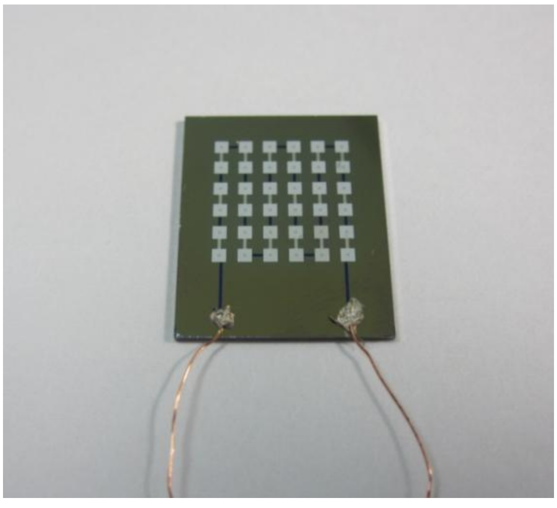

Fig. 1: Fabricated μ-TEG.

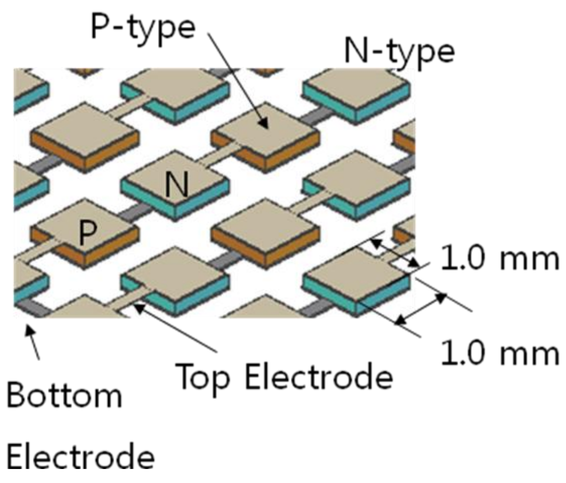

Fig. 2: Structure of the μ-TEG.

When a temperature difference occurs between the top and the bottom surfaces of the micro TEG columns, voltage is generated from each P-type and N-type column by the Seebeck effect [7]. If the hot side and cold side temperatures are T_h and T_c, respectively, the electrical voltage V can be obtained by using a following equation,

$$V = \alpha \cdot (T_h - T_c) \quad (1)$$

where α is the Seebeck coefficient [7]. In our device, the voltage from each column is summed together through the serial electrical path, and the summed voltage can be obtained at both end of the circuit.

FABRICATION

Fabrication processes of the μ-TEG are explained in Fig. 3. These involve the deposition of titanium nitride (TiN), poly-Si chemical vapor deposition (CVD), aluminum (Al) Sputtering, ion-implantation, photo-lithography, Al etch and poly-Si etch.

In the first step, a 0.2 μm thick oxide layer was deposited on a 525 μm bare Si wafer. The oxide layer was thermally grown using a chemical vapor deposition (CVD) system. And a 0.2 μm thick TiN layer as a bottom metal electrode was deposited onto the pre-deposited 0.02 μm thick titanium (Ti) layer, which is an adhesion layer between the TiN films and the oxide layer. Subsequently, 0.3 μm thick poly-Si films were deposited on a 0.2 μm thick TiN layer, which helps poly-Si films to be deposited well on the oxide layer. The poly-Si layer was fabricated with a 60 sccm flow of the silane (SiH_4) gas under a pressure of 200 μbar. The temperature was 620˚C and the deposition rate was 8.5 nm/min.

In the second step, ion implantation processes were performed for the thermoelectric characteristics of the poly-Si films. For P-type properties, boron ions were implanted with the energy of 50 keV and the dopant dose of 10^{16} cm^{-2}. And phosphorous ions were implanted with 130 keV energy and 10^{15} cm^{-2} dopant dose for N-type properties.

At the third step, a 0.15 μm thick Al layer was sputtered on the pre-deposited 0.02 μm thick Ti adhesion layer for the upper electrodes. The applied power for this sputtering process was 500 W and the temperature was 0 ˚C. After a photolithography process, Ti/Al layers were patterned with the dry etching process for the top electrode patterns. Then, the poly-Si and the TiN layers were etched for the column shapes and the bottom electrodes, respectively.

For an electrical insulation, a 0.15 μm thick tetra ethoxy silane (TEOS) oxide layer was deposited on the patterned wafer. The oxide layer was deposited using low pressure chemical vapor deposition (LPCVD). The flow rate of the TEOS gas was 30 sccm under a pressure of 267 μbar. The temperature was 713˚C and the deposition rate was 8.5 nm/min. Then via-holes were patterned for electrical connections of the top electrodes and the thermoelectric columns through the insulation layer.

Finally, for the connecting patterns between top electrodes of P-type and N-type columns, Al Sputtering was processed. Another 0.15 μm thick Al layer was sputtered on the patterned wafer with the same condition for the previous Al deposition. After a photolithography process, Al layers were patterned with the dry etching process for the connecting patterns. After patterning, 14 × 17 mm specimens were obtained by a dicing process.

EXPERIMENTS

After fabrication, thickness of each layer was inspected with scanning electron microscopy (SEM) pictures. The SEM picture of the μ-TEG is shown in Fig. 4 and it proved that measured thicknesses agreed well with the designed values, which were 150 /150 /100 /300 /200 /200 nm for Al /SiO_2 /Al /Poly-Si /TiN /SiO_2 films from the top, respectively.

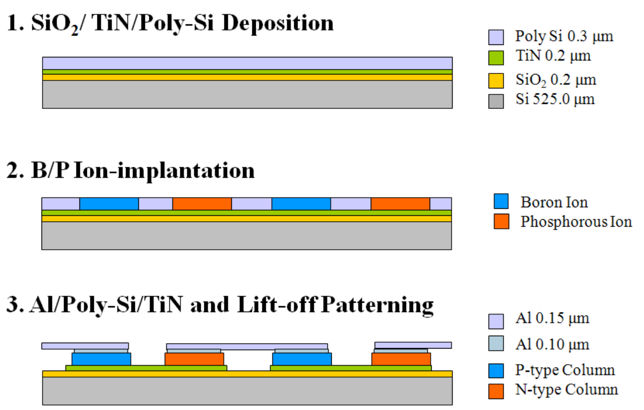

Fig. 3: Fabrication processes.

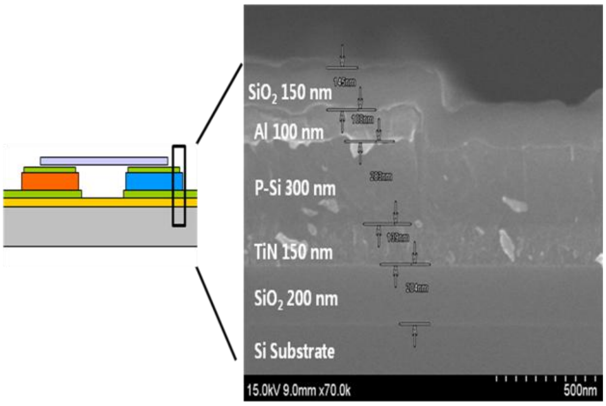

Fig. 4: SEM picture of the μ-TEG.

The transport properties such as Seebeck coefficient and electrical conductivity were measured at room temperature. Using these results, thermoelectric power factor, TPF was calculated using an equation as follows,

$$TPF = \alpha^2 \cdot \sigma \quad (2)$$

where σ is an electrical conductivity [7]. The calculated results are listed in Table 1. The evaluated TPFs of the P-type and the N-type Poly-Si films were 527 $\mu Wm^{-1}K^{-2}$ and 1160 $\mu Wm^{-1}K^{-2}$, respectively.

Additionally, for the assessment of device performance, the figure of merit was measured using an experimental setup as shown in Fig. 5. The figure of merit, ZT is defined as,

$$ZT = \alpha^2 \cdot \sigma T / \lambda \quad (3)$$

where T is an environment temperature and λ is a thermal conductivity, respectively [7].

The measured figure of merit was 0.873 at an environment temperature of 21.4˚C and the applied current of 5mA. As a conclusion, the developed μ-TEG is likely to be an energy source from the wasted heat and expected to raise the energy efficiency.

Table 1: Power factor.

Type	Seebeck Coefficient, α (mVK^{-1})	Electrical Conductivity, σ ($\Omega^{-1}m^{-1}$)	Power Factor, $\alpha^2\sigma$ ($\mu Wm^{-1}K^{-2}$)
P-type	0.393	3421	527
N-type	-0.390	7642	1160

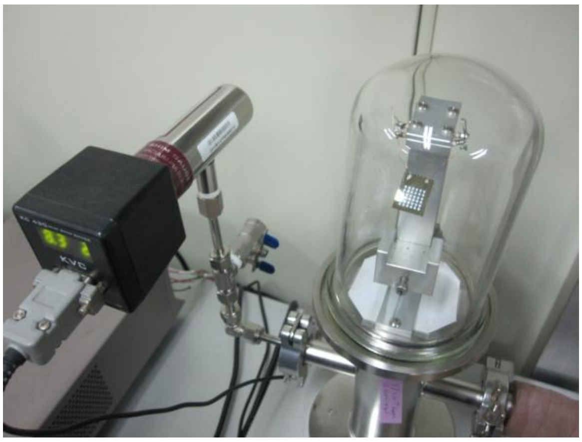

Fig. 5: Experimental setup for measuring figure of merit.

RESULTS AND DISCUSSION

The experimental results of power factors of 527 $\mu Wm^{-1}K^{-2}$ and 1160 $\mu Wm^{-1}K^{-2}$, for the P-type and the N-type show that the conventional semiconductor material poly-Si films can be a thermoelectric layer for μ-TEG device. In addition, the measured figure of merit value of 0.873, is another experimental result that explains the power generation performance of the poly-Si films.

Based on these results, the developed μ-TEG is thought to be manufactured with reduced cost by the mass production using conventional semiconductor fabrication technologies. At the end, the developed μ-TEG is expected to be an alternative energy source for mobile devices using the wasted heat.

CONCLUSION

In this research, semiconductor process compatible micro TEG having low production cost and higher performance efficiency was developed. The structure of the μ-TEG was described with working principles. The fabrication processes were explained with detailed deposition or etching conditions.

The transport properties of Seebeck coefficient and electrical conductivity were measured. And power factors were obtained as 527 $\mu Wm^{-1}K^{-2}$ and 1160 $\mu Wm^{-1}K^{-2}$, for the P-type and the N-type Poly-Si films, respectively. Additionally, the figure of merit was measured using an experimental setup as 0.873. As a conclusion, the poly-Si μ-TEG is thought to be a portable energy generation device using the wasted heat with raised energy efficiency.

ACKNOWLEDGEMENT

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REFERENCES

[1] Strasser M. Aigner R, Lauterbach C, Sturm T F, Franosch M and Wachutka G 2004 Micromachined CMOS thermoelectric generators as on-chip power supply *Sens. Actuators A* **114** 362-370

[2] Zeng G, Bowers J E, Y Zhang and Shakouri A SiGe/Si superlattice power generators *Proc. of 24th Int. Conf. on thermoelectric (Clemson, SC, USA, 2005)* 164-167

[3] Posthill J, Reddy A, Siivola E, Krueger G, Mantini M, Thomas P, Venkatasubramanian R, Ochoa F and Ronney P Portable power sources using combustion of butane and thermoelectrics *Proc. of 24th Int. Conf. on thermoelectric (Clemson, SC, USA, 2005)* 517-520

[4] Kiely J J, Morgan D V and Rowe D M 1991 Low cost miniature thermoelectric generator *Electronics Letters* **27** 2332-2334

[5] Strasser M, Aigner R, Franosch M and Wachutka G, 2002 Miniaturized thermoelectric generators based on poly-Si and poly-SiGe surface micromachining *Sens. Actuators A* **97-98** 535-542.

[6] Glatz W, Schwyter E, Durrer L and Hierold C 2009 Bi_2Te_3-based flexible micro thermoelectric generator with optimized design *J. of Microelectromech. Syst.* **18** 763-772

[7] Rowe D M 2006 *Thermoelectrics Handbook: Macro to Nano* (Boca Raton, FL, USA, CRC Press)