

# Substrate-Free $\text{Y}_3\text{Fe}_5\text{O}_{12}$ (YIG) Spin-Thermoelectric (TE) Module Prepared by the Sol-Gel Synthesis

Min-Sun Jang<sup>1,3\*</sup>, Im-Jun Roh<sup>2</sup>, Jungmin Park<sup>3</sup>, Chong-Yun Kang<sup>2,6</sup>, Won Jun Choi<sup>4</sup>,  
Seung-Hyub Baek<sup>2,5</sup>, Kyoung Jin Choi<sup>1</sup>, Sung Soo Park<sup>3</sup>, Jung-Woo Yoo<sup>3</sup>, Ki-Suk Lee<sup>1,3†</sup>

<sup>1</sup>KIST-UNIST Ulsan Center for Convergent Materials, Ulsan National Institute of Science and Technology (UNIST),  
Ulsan 44919, Republic of Korea

<sup>2</sup>Center for Electronic Materials, Korea Institute of Science and Technology (KIST), Seoul 02792, Republic of Korea

<sup>3</sup>School of Materials and Science Engineering, Ulsan

National Institute of Science and Technology (UNIST), Ulsan 44919, Republic of Korea

<sup>4</sup>Center for Opto-Electronic Materials and Devices,

Korea Institute of Science and Technology (KIST), Seoul 02792, Republic of Korea

<sup>5</sup>Department of Nanomaterials Science and Technology,

Korea University of Science and Technology, Daejeon, 34113, Korea

<sup>6</sup>KU-KIST Graduate, School of Converging Science and Technology, Korea University, Seoul 02841, Korea

## 1. Introduction

Recently, magnetic materials and magnetic phenomena continuously have been highlighted as prominent resource for a future green energy [1, 2]. The ferrimagnet insulator- $\text{Y}_3\text{Fe}_5\text{O}_{12}$  (YIG) that is the one of the magnetic material with metal oxides has been taken center stage owing to its prominent applications to eco-friendly spin-caloritronics [3, 4]. During the past decade, most of the studies on the spin Seebeck effect (SSE) have been done on well-grown single crystal sample of YIG by pulsed laser deposition (PLD) method [5]. Here, we report on the SSE of YIG prepared by a sol-gel method, a conventional method for metal oxide materials [6, 7]. In this presentation, we reveal that the temperature of heat treatment and effect of the external mechanical pressure can play a critical role for the magnetic properties of YIG. Furthermore, we demonstrate that considerable spin thermoelectric voltage can be generated successfully by the poly crystal – YIG prepared by the sol-gel method.

## 2. Experiments

We prepared the YIG precursor by mixing yttrium nitrate ( $\text{Y}(\text{NO}_3)_3 \cdot 6\text{H}_2\text{O}$ , 99.99%) and iron nitrate ( $\text{Fe}(\text{NO}_3)_3 \cdot 9\text{H}_2\text{O}$ , 99.99%) powders in a stoichiometric ratio of 3: 5, and adding citric acid ( $\text{C}_6\text{H}_8\text{O}_7 \cdot \text{H}_2\text{O}$ ). The precursor mixture was dissolved in distilled water (100 mL) by stirring (300 rpm) at 27 °C for 18 hours. The solution of the citric acid was maintained at 1pH. The resulting solution (sol) was then stirred for 24 hours at 80 °C to obtain a homogenous gel. Next, a gel was obtained from the sol by drying the solution, which was decomposed at 100 °C for 5 hours to form a dry material. The YIG powder was obtained by grinding the completely dried gel for 30 min. The calcination process was carried out at 850 °C in the air for 2 hours at a heating rate of the 7.7 °C /min to get rid of residual impurities and the crystallization. After, we did the pressing process to produce the substrate-free YIG by pushing 1.5 ton for 5 minutes and to check out the influence of external mechanics for magnetic properties. Lastly, sintering has been done at 1400 °C for 4 hours. After produced the substrate-free YIG, we designed the platinum (Pt) on the surface of the YIG because of observing the longitudinal SSE. The 15 nm-Pt layer was deposited on the disk-shaped YIG with 1.8 mm thickness and 14

mm diameter. And 400 Oe magnetic field applied parallel to the disk plane and the temperature gradient was formed along out-of-plane direction. We produced not only the substrate-free spin-TE module but also investigated various materials properties of the YIG.

### 3. Results & Discussion

After pressing, the microstructure resembled a continuous network of almost hexagonal bubble-shaped particles with no vacancies. The field-emission scanning electron microscopy (FE-SEM; Hitachi, S-4800) images indicate that mechanical pressing after the heat treatments results in grain growth with high densification and a remarkable reduction of impurities in the microstructure. The particles become coarser as the sintering time was increased. Moreover, we found from X-ray diffractometer (XRD; Bruker AXS, D8 ADVANCE) and X-ray photoelectron spectroscopy (XPS; ThermoFisher, K-alpha) measurements that the extra surface energy induced by the pressing and sintering process allows the complete crystallization of polycrystalline YIG to be achieved by increasing the degree of oxidation. Consequently, the  $M_s$  was enhanced from 10 emu/g to 26.5 emu/g after the pressing process. From the measurement of the spin-TE module, we observed that the considerable spin thermoelectric voltage was generated successfully. This research might be suggested how to make easily and inexpensively YIG with enhanced magnetic properties as well as the applicable spin-TE module.

### 4. References

- [1] M. Hatami et al., Phys. Rev. Lett. **99**, 066603 (2007).
- [2] X. Yu et al., Nat. Mat. **15**, 383 (2016).
- [3] K. Uchida et al., Nat. Mat. **9**, 894 (2010).
- [4] K. Uchida et al., J. Phys.: Condens. Matter **26**, 343202 (2014).
- [5] N. B. Ibrahim et al., J. Magn. Magn. Mater. **220**, 183 (2000).
- [6] R. Kuchi et al. Nanosci. Nanotechnol. Lett. **7**, 738 (2015).
- [7] H. Adachi, Phys. Rev. B **83**, 094410 (2011).