

# IMPACT TRIGGERED THERMOELECTRIC POWER GENERATION WITH PHASE CHANGE ASSISTED TEMPERATURE GRADIENT ENHANCEMENT

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**Abstract:** This paper demonstrates an impact triggered thermoelectric generation (IT-TEG) utilizing the liberated latent heat resulting from crystallization of supersaturated sodium acetate trihydrate (SSAT). This results in an enhanced thermal gradient which increases the output electrical power. The fabrication process includes standard molding and laser machining. Supersaturated sodium acetate in IT-TEG is encapsulated in a polydimethylsiloxane (PDMS) chamber with a steel cap covering the top. Impact/snap applied to the steel cap triggers the exothermic crystallization reaction, releasing the latent heat and delivering the thermal energy to the thermoelectric module. SSAT can reach up to 54 °C which can achieve an instantaneous output power of 16.9  $\mu$ W.

**Keywords:** Supersaturated sodium acetate trihydrate, thermoelectric generator, crystallization.

## INTRODUCTION

Power generation via thermoelectric modules has been investigated for several decades [1]. More recently, miniature versions of such systems have been the focus of intense research [2-5]. Most such efforts have been geared toward integration of thermoelectric material with MEMS structures. Recently, we demonstrated a novel concept to increase the available temperature gradient using evaporative cooling triggered by body heat [6]. However, the improvement in performance was limited by attainable temperature gradient ( $\sim 16$  °C). In this paper, we report on an alternative embodiment in which a reversible exothermic reaction (crystallization of a supersaturated sodium acetate trihydrate) is used to heat one of the junctions to 54 °C, almost doubling the temperature gradient as compared with our previous device. We should mention that in present design a mechanical impulse is required to trigger the reaction which allows the system to be used in environments that can subject the device to rapid acceleration/deceleration or snap action.

## DESIGN

A thermoelectric device generates a voltage when there is a temperature difference between its junctions. This can be achieved by either heating one side or cooling down the other, or both. In our design, we used latent heat stored in a phase change material as the source of thermal energy to achieve a higher temperature difference. Specifically, we used supersaturated sodium acetate trihydrate (SSAT,  $\text{CH}_3\text{COONa} \cdot 3\text{H}_2\text{O}$ ) as the phase change liquid.

Sodium acetate trihydrate (SAT) is a crystalline

solid which melts at 54 °C by dissolving in water of crystallization. However, it is possible to cool down liquid SAT to room temperature without forming solid crystals. Hence, it can be used as stable phase change liquid that stores thermal energy in the form of latent heat [7]. To release this energy, one needs to start the phase conversion which can be triggered by creating a nucleation site in the liquid. A large mechanical impact (e.g., drop from a height or simple manual clicker) can force formation of first crystal nuclei which triggers the exothermic solidification process. Alternatively, one can introduce some impurity to the solution, which also can act as a trigger. Once the process starts, it does not stop until all the liquid is crystallized releasing stored latent heat to increase the temperature close to its melting point ( $\sim 54$  °C). Being

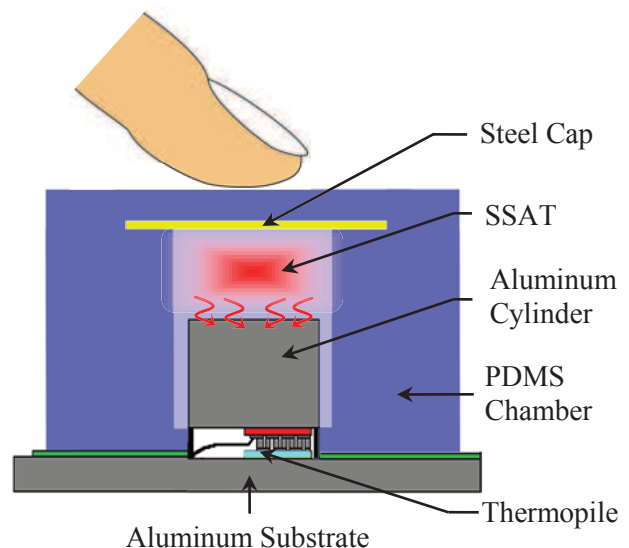


Figure 1: Basic structure of IT-TEG

a thermodynamically reversible process, crystalline sodium acetate can be heated again to liquefy and store thermal energy.

Figure 1 shows the basic structure of IT-TEG. The thermoelectric module is enclosed in an aluminum casing to protect it from direct exposure to sodium acetate. Aluminum is chosen because of its high thermal conductivity and easy machining. Top aluminum cylinder is surrounded by SSAT contained inside a PDMS chamber. Bottom aluminum substrate is exposed to surroundings environmental temperature. When exothermic solidification process is triggered, temperature rises to 54 °C in matter of seconds. Since PDMS is a poor conductor of heat, energy lost to the surroundings is limited and most of it is used to increase the temperature of the TEG top surface.

### FABRICATION

Figure 2 shows the fabrication process for the device. It starts with laser machining of acrylic (Fig. 2a) to create a mold for casting of PDMS chamber (Fig. 2b-c). A CO<sub>2</sub> laser (Universal Laser Systems) was used to machine acrylic. A hole was then punched through the bottom of PDMS chamber (Fig. 2d) to achieve a snug fit around the TEG module (TGP-651, Micropelt, Germany) (Fig. 2e). After mounting the PDMS chamber on top of the aluminum cylinder, liquid SSAT was poured inside (Fig. 2f). It is important to make sure the chamber is clean before pouring SSAT because even a small amount of impurity can trigger the crystallization process. Once

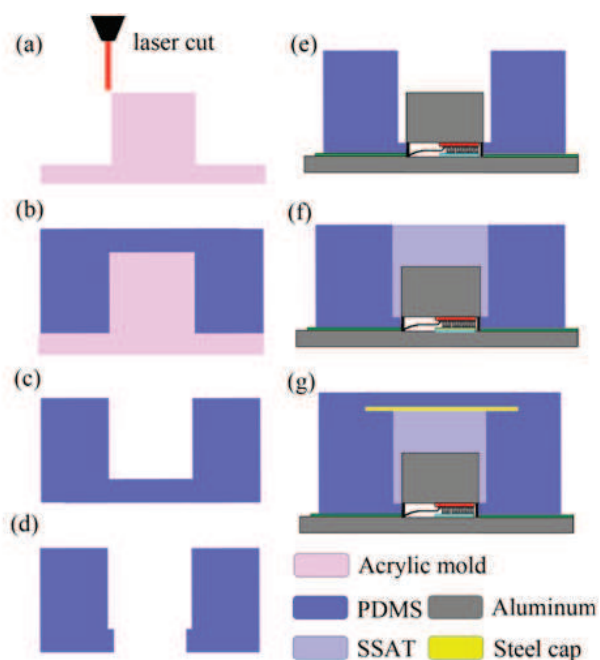


Figure 2. Fabrication process of the impact triggered thermoelectric power generator

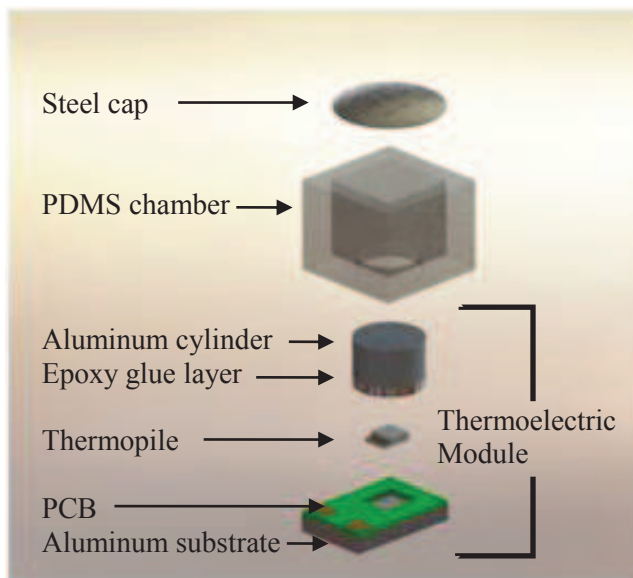


Figure 3. Exploded view of the device showing various components.

solidified, SAT can't encapsulate TEG effectively, leaving trapped air-pockets that prevent heat transfer. Top of the PDMS chamber was closed by a steel cap (diameter = 16.6 mm) and a thin layer of uncured PDMS was applied to seal the chamber (Fig. 2g). The steel plate is designed such that it snaps when pressed providing an impulse to initiate the crystallization.

Figure 3 shows 3D schematic of the device in an exploded view including TEG module, PDMS chamber, and steel cap. The TEG module consists of a silicon Peltier chip (MPG-D651, Micropelt, Germany) at the center which is surrounded by an aluminum casing (cylinder on top and rectangular block at the bottom). The cylinder and the bottom block are thermally isolated by a layer of epoxy which also

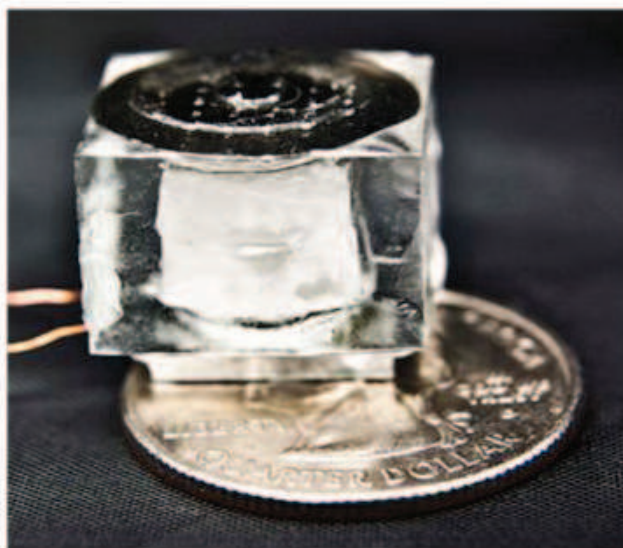


Figure 4. Photograph of a device with 10 × 10 × 10 mm<sup>3</sup> chamber

keeps the whole assembly together. The contacts are brought outside using a PC board. Since aluminum is a good conductor of heat, the casing provides protection to the chip without significant loss in temperature. Figure 4 shows photograph of the final fabricated device.

## MEASUREMENTS

In order to understand the relationship between the amount of SSAT and voltage output, different sizes of PDMS chambers were fabricated. Chamber depth was kept constant at 10 mm and cross-sectional size was varied from  $9 \times 9 \text{ mm}^2$  to  $15 \times 15 \text{ mm}^2$ . In every case chamber was filled to the top.

Before the measurements, all the devices were maintained at room temperature. Crystallization was initiated by clicking the steel releasing latent heat of fusion. Figure 5 (a-d) shows a series of snap-shots following the trigger clearly demonstrating the crystallization process. This process increases the temperature of solution to  $54^\circ\text{C}$  (melting point of sodium acetate) which in turn heats up hot junction through the aluminum cylinder creating thermal gradient against the cold junction which is at room temperature ( $21^\circ\text{C}$ ). Voltage generated by this thermal gradient was measured by connecting a  $100 \text{ k}\Omega$  load across IT-TEG module.

## RESULTS AND DISCUSSION

Figure 6a shows the measured voltage vs. time. As can be seen, in all the cases output voltage rises quickly to its maximum value and slowly drops to a

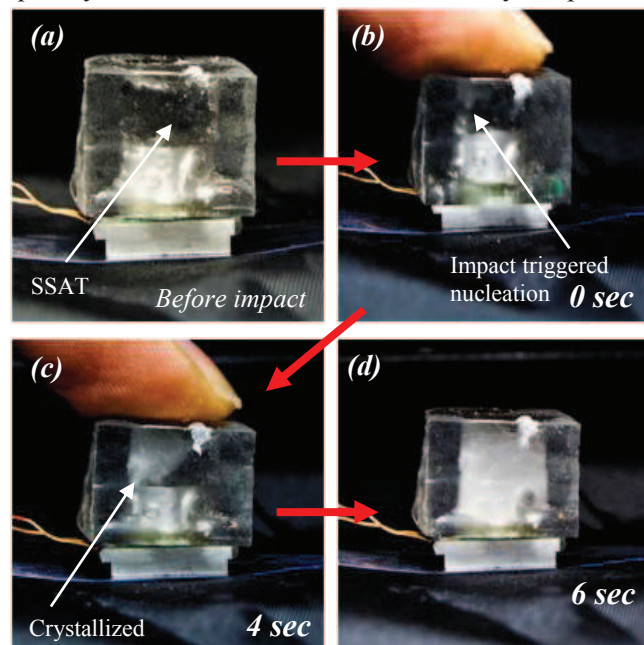


Figure 5. Snap shots of sodium acetate trihydrate crystallization process after impact trigger.

lower level. Immediately after trigger, as SSAT starts solidifying, temperature of the hot junction increases. Considering initial temperature of crystallized SAT ( $54^\circ\text{C}$ ) one can obtain a maximum temperature difference of  $33^\circ\text{C}$  against the room temperature ( $21^\circ\text{C}$ ). Based on a Seebeck coefficient of  $60 \text{ mV/K}$  [8] TGP-651 can generate up to  $1.98 \text{ V}$ . However, this theoretical value does not account for heat lost to the surroundings and heat conducted to the cold junction, which affect desired temperature gradient adversely. Therefore, the maximum measured voltage ( $1.3 \text{ V}$ ) was lower than the theoretical value. Further, this maximum output is not maintained due to transient nature of the process. As the time progresses, heat is also conducted to the cold junction resulting in lower thermal gradient. At equilibrium, whole system reaches a uniform temperature and voltage drops to zero.

Figure 6b shows maximum voltage output obtained for various sizes of the PDMS chamber. Initially, the output voltage increases with the chamber size is increased, saturating at  $1.25 \text{ V}$  for larger chambers.

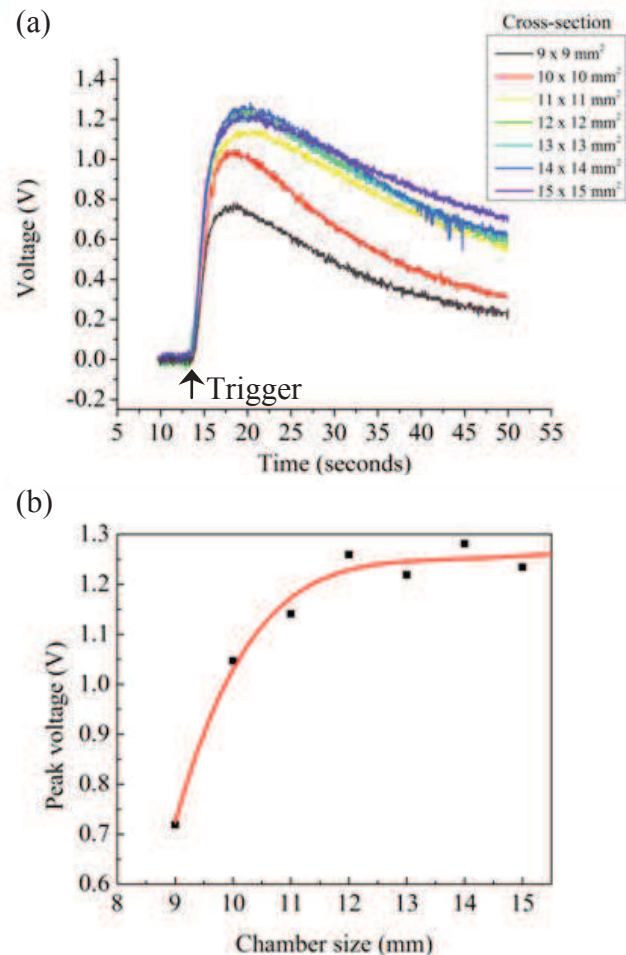


Figure 6. (a) The output voltage across a  $100 \text{ k}\Omega$  load with various amounts of sodium acetate trihydrate. (b) Peak voltage vs. chamber size.

Although temperature resulting from crystallization of SAT is always 54 °C, small amount of SAT may not have sufficient thermal energy to heat up the aluminum cylinder and hot junction to the maximum temperature. As the amount of SSAT is increased higher temperatures can be achieved with the highest voltage limited by melting point of SAT (54 °C).

## CONCLUSIONS

We have developed a thermoelectric power generating device with enhanced thermal gradient utilizing latent energy stored in a phase change liquid. The process can be initiated by a mechanical impulse provided by snapping action of steel plate or impact against the wall. With SSAT as the phase change liquid, single IT-TEG can generate output voltage of up to 1.3 V and instantaneous power up to 16.9  $\mu$ W. Simple and robust design, coupled with good voltage output, make the use of phase change liquid an attractive choice for improving performance of TEG devices.

## REFERENCES

- [1] Decher R. 1996 *Direct Energy Conversion: Fundamentals of Electric Power Production* (USA, Oxford University Press)
- [2] Leonov V., Torfs T., Fiorini P., Van Hoof C. 2007 Thermoelectric Converters of Human Warmth for Self-Powered Wireless Sensor Nodes *IEEE Sensors Journal*. 7 650–657
- [3] Xie J., Lee C., Feng H. 2010 Design, Fabrication, and Characterization of CMOS MEMS-Based Thermoelectric Power Generators *Journal of Microelectromechanical Systems*, 19 317–324
- [4] Ghafouri N., Kim H., Atashbar M. Z., Najafi K. 2008 A Micro Thermoelectric Energy Scavenger for a Hybrid Insect *IEEE Sensors (Lecce, 26–29 October 2008)* 1249–1252,
- [5] Minnich A. J., Dresselhaus M. S., Ren Z. F., Chen G. 2009 Bulk Nanostructured Thermoelectric Materials: Current Research and Future Prospects *Energy & Environmental Science*, 2 466–479
- [6] Mousoulis C., Yoon C. K., Chitnis G., Ziaie B. 2012 Thermoelectric Energy Scavenging with Temperature Gradient Amplification *IEEE Proc. MEMS* 1285-1288
- [7] Wada T., Kimura F., Matsuo Y. 1983 Studies on Salt Hydrates for Latent Heat Storage. IV. Crystallization in the Binary System  $\text{CH}_3\text{CO}_2\text{Na}-\text{H}_2\text{O}$  *Chemistry Society of Japan* 3827–3829
- [8] [http://www.micropelt.com/download/themo\\_generator\\_package.pdf](http://www.micropelt.com/download/themo_generator_package.pdf), Webpage accessed on Oct., 2012