

# 자가발전 섬유/직물 기술 -열전 발전기

(Electricity Generating Textiles-Thermoelectric Energy Harvesting)

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# 개요

- 광범위한 자극 감지, 적합한 기능을 직물 및 의류에 제공할 수 있어 웨어러블 디바이스 및 스마트 섬유는 많은 분야에서 연구되거나 사용되고 있다. 현재 가장 잘 알려진 장치로는 운동 선수, 노약자, 환자, 소방관 및 우주 비행사의 신체 능력을 모니터링하는 것이다.
- 이러한 웨어러블 디바이스가 해결해야 할 주요 과제는 꾸준히 전원을 공급하는 것이다. 대부분의 장치들은 기존의 충전식 배터리를 사용하여 전원을 공급하고 있으나 기존의 배터리는 무겁고 부피가 크기 때문에 유연성이 떨어지거나 세탁 후 재사용이 불가능한 단점이 있다. 이러한 단점은 직물이나 의류 제품 고유의 특성을 이용하지 못하는 문제점이 있다.
- 의류나 직물과 같은 기판에 전력을 공급하기 위한 기존 배터리의 문제점을 해결하는 방법으로는 전력을 스스로 발생시키는 방법이 있으며 직물이나 의류는 자가 발전을 적용하기에 적합한 이점들을 가지고 있다.
- 자가 발전의 방법 중의 하나는 열전 발전이 있으며, 현재 큰 열전 효과를 나타내는  $\text{Bi}_2\text{Te}_3$  이나  $\text{Sb}_2\text{Te}_3$ ,와 같은 재료의 단점으로 인해 섬유/직물 기반 열전 발전 소자 개발에 어려움이 있다.
- 열전 발전 소자의 단점을 보완하기 위해 다양한 방법이 연구되고 있으며 직조 과정에서 열전 성능을 지닌 와이어를 삽입하는 기술 등 다양한 기술들이 연구 및 개발되고 있다.

# 열전 효과

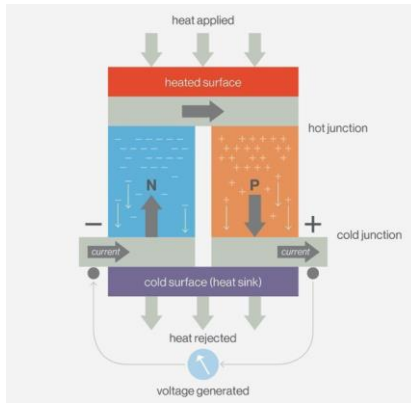


Fig 1. The seedbeck effect

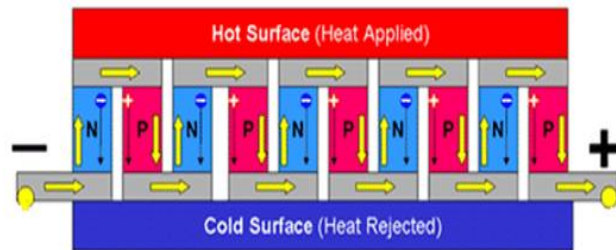


Fig 2. Principle of operation of a thermoelectric generator

- The thermoelectric effect is generally used to convert thermal energy into electric energy.
- The most explored thermoelectric devices convert temperature gradients ( $dT/dx$ ) to electric energy through the Seebeck effect.
- A high temperature gradient or fluctuation is preferred, and thus thermoelectric devices are rarely used in wearable electronics.
- A thermoelectric power generator has a simpler structure than a solar cell. It is basically composed of thermoelectric material and positive/negative electrodes.
- There are two methods to fabricate thermoelectric textiles, either conventional brittle thermoelectric materials are coated on flexible substrates or flexible thermoelectric materials are used directly



# 섬유형 열전 발전기(Fiber-Shaped Thermoelectric Generator)

Table 1. Summary of methods for preparation of Thermoelectric fibers

Methods	Materials
Wet spinning <sup>[16,25,31,32,34]</sup>	PEG/CNT, PVDF/CNT, PEDOT:PSS/CNT, Graphene
Aerogel spinning <sup>[28]</sup>	CNT
Gelation process <sup>[33]</sup>	PEDOT:PSS
Extrusion technique <sup>[26]</sup>	$\text{Bi}_{0.5}\text{Sb}_{1.5}\text{Te}_3$ , $\text{Bi}_2\text{Te}_{2.7}\text{Se}_{0.3}$
Electrospinning and Magnetron sputtering <sup>[22]</sup>	$\text{Sb}_2\text{Te}_3$ - $\text{Bi}_2\text{Te}_3$
Thermal drawing technique <sup>[23,35,37-39]</sup>	$\text{Bi}_{0.5}\text{Sb}_{1.5}\text{Te}_3$ - $\text{Bi}_2\text{Se}_3$ , $(\text{Te}_{85}\text{Se}_{15})_{45}\text{As}_{30}\text{Cu}_{25}$ , $\text{In}_4\text{Se}_3$ , $\text{Bi}_2\text{Te}_3$
Casting (yarn/filament/fiber as substrate)	
Drop-casting <sup>[36]</sup>	PVP/CNT
Dip-coating <sup>[27,29,40]</sup>	WPU/PEDOT:PSS/CNT, PEDOT:PSS, P3HT
Thermal evaporation <sup>[24]</sup>	Ni-Ag

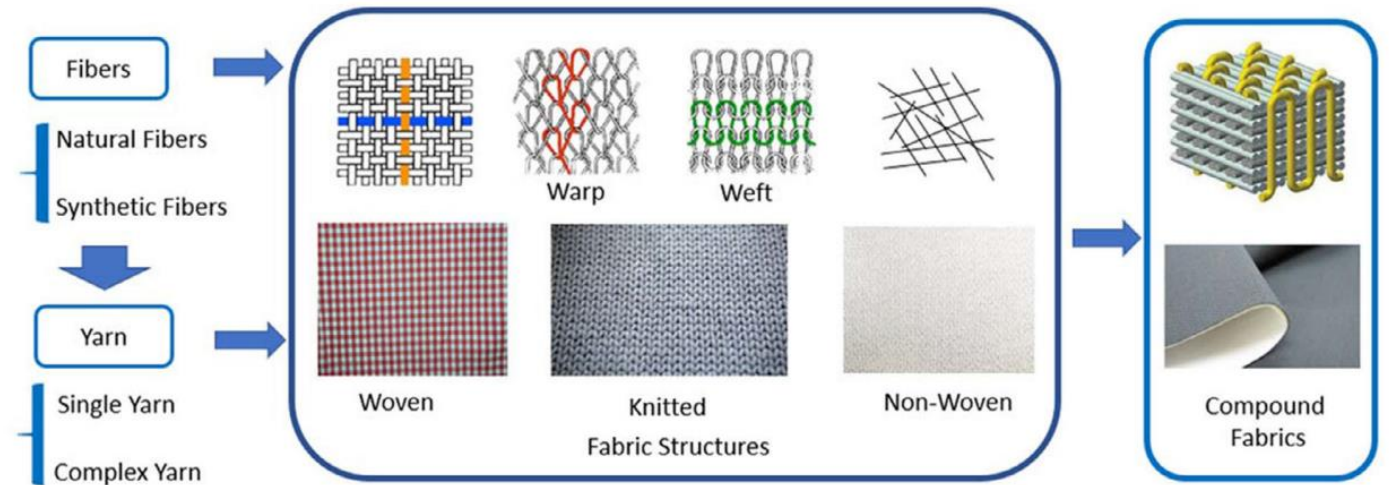


Figure 3. Summary of methods for preparation of Thermoelectric fibers

- The commonly used materials in TE(Thermoelectric) fibers can be divided into two types, one is conventional inorganic TE materials, and another is organic TE materials including conductive polymers and related composites as well as carbon nanocrystal-based materials.

# 섬유형 열전 발전기(Fiber-Shaped Thermoelectric Generator)

- Organic TE materials are generally solution-processible, and thereby, they can be manufactured into fibers by spinning techniques or facile solution-coating methods: Wet spinning, Aerogel spinning et al.
- Conventional inorganic TE materials are rigid and brittle so that they are hard to be directly manufactured into flexible and freestanding fibers.

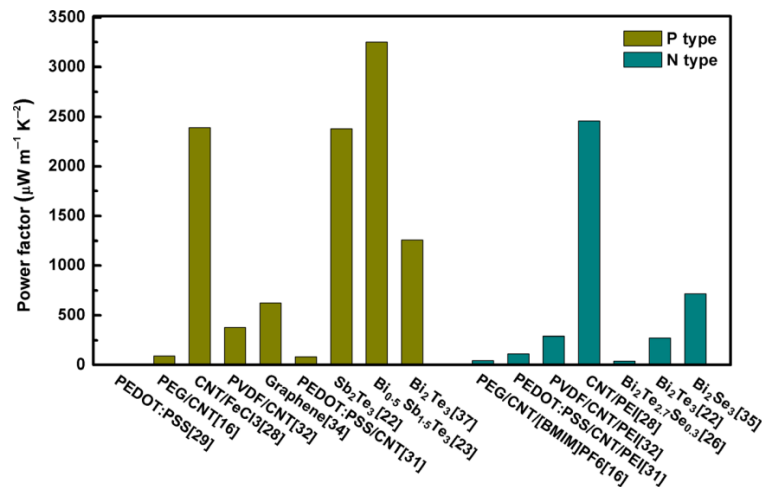


Fig 4. Room temperature power factors of typical organic and inorganic TE fibers

- Fig 4 summarizes the power factors of typical organic and inorganic TE fibers. The power factors of most inorganic TE fibers are much higher than that of organic ones.
- Although the power factors of some CNT- or graphene-based fibers were very high, but the probably high thermal conductivity can lead to very low  $zT$  values. It is noted that CNT-based TE fibers can be converted from p type to n type after simple post-treatment with n-type dopants such as PEI and [BMIM]PF<sub>6</sub>.

# 섬유형 열전 발전기(Fiber-Shaped Thermoelectric Generator)

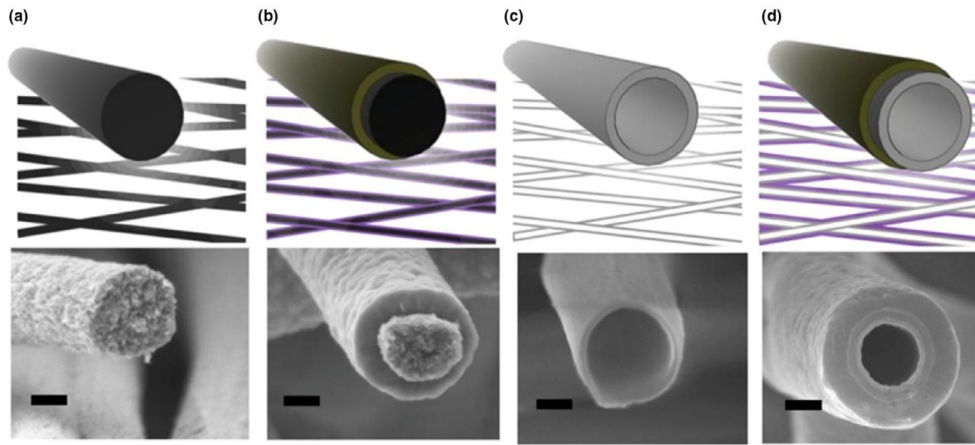


Figure 5. a) The electrospun carbon nanofiber, b) poly-silicon layer on the carbon nanofiber, c) silicon oxide nanotube after annealing of the carbon nanofiber, d) poly-silicon layer coating the silicon oxide nanotube. Scale bars are 200 nm.

- Similar to the preparation of TE fibers by using commercial fiber, Other fiber-shape TEs are obtained by coating fabrics with organic or inorganic materials.
- Unlike commonly used coating methods, Morata et al. presented a scalable manufacturing method and cost-effective TE fabrics. A case of TE fabric made up of p-type silicon nanotubes was fabricated by depositing silicon layers onto sacrificial substrates of electrospun carbon nanofibers(Fig 5a).
- Then, it was used as sacrificial template and coated by polysilicon layer(Fig 5b). After calcination, the carbon core was removed and the silicon shell was oxidized, producing silicon oxide nanotube(Fig 5c).
- Finally, the active poly-silicon layer was deposited onto the silicon oxide nanotube(Fig 5d). The flexible TE fabric displayed the highest  $zT$  value of 0.34 among silicon-based macroscopic materials at 550°C. This method is providing a new approach for manufacturing high-performance fabric-based TEGs in the future.

# 직물형 열전 발전기(Textile-Shaped Thermoelectric Generator)

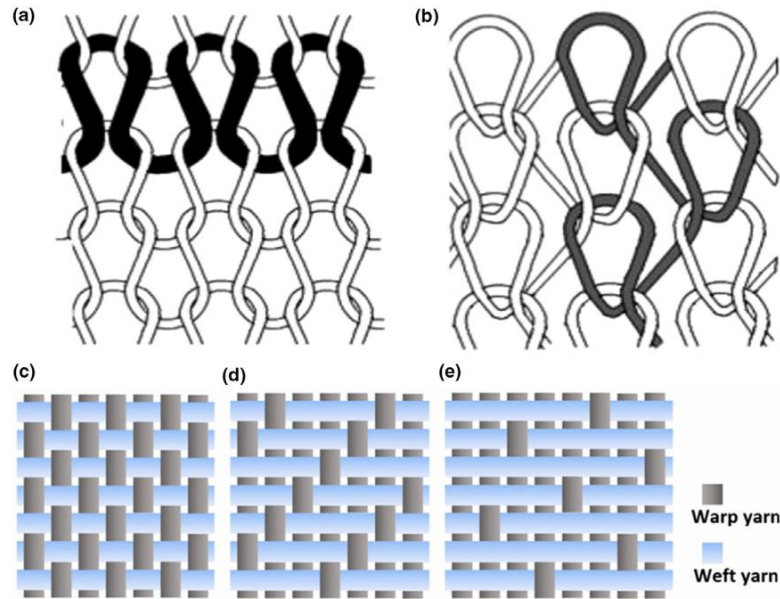


Fig 6. Two typical knitted structure: a) Weft knitting and b) warp knitting. Three typical woven structures: c) plain weave, d) twill weave, and e) satin weave.

*“Textile-Based Thermoelectric Generators and Their Applications”, L. Wang & K. Zhang.*

- In fact, the temperature difference between human body and ambience is vertical to skin. Textile-shaped TE generators can sufficiently harvest thermal energy and are easily integrated into textiles for wearable electronics.
- Knitting is a method to produce stretchable and soft fabrics by interlocking loops of yarns. There are two main knitting methods: weft knitting (Fig 6a) and warp knitting (Fig 6b). The knitted fabrics showing ultrahigh elasticity up to 500% are much more flexible than other types of fabrics.
- Weaving is another industrial textile production method. Different weaving methods can result in various textile structures, including plain weave, twill weave, and satin weave, as shown in Fig 6c–e.
- The state-of-the-art TE materials with excellent thermoelectric properties at room temperature are bismuth telluride-based alloys. These inorganic TE ingots are commonly assembled into fabrics by printing methods to achieve flexible textile-shaped TE generator.
- For example, Shin et al. also coated TE thick films onto fabrics by screen printing method.[56] The proper selection of suitable binder provides desired viscosity at very low additive loading, and the printed p-type  $\text{Bi}_{0.5}\text{Sb}_{1.5}\text{Te}_3$  and n-type  $\text{Bi}_2\text{Te}_{2.7}\text{Se}_{0.3}$  films displayed high  $zT$  values of 0.65 and 0.81.



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