Nanostructured oxide semiconductors grown on fabric for wearable thermoelectric power generator with UV shielding

（課程博士・様式 7）（Doctoral qualification by Coursework, Form 7）

学位論文の要旨

Abstract of Doctoral Thesis

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論文題目：

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Abstract：

Clothing and textile materials are the elements that are almost always present and is customizable to each human being. In the last few years, the smart textiles feature such as stain resistance, antimicrobial, superhydrophobic/ super-hydrophilic, antistatic, sensors, power generators, electromagnetic/ ultraviolet interference shielding, wrinkles resistant, and shrink-proof abilities. Since the energy and environmental efficiency governance are becoming the demand, there is a need for alternate renewable energy conversion system that will reduce the greenhouse gases emission and improve the energy competence.

The eco-friendly renewable energy source for smart textile from various environmental origin such as photovoltaic (PV) utilizing the light source, thermoelectric (TE) employs temperature difference, piezoelectric (PE) proving kinetic energy from vibrations or shocks and radio frequency (RF) energy were accepting moving waves of electric and magnetic together. The ability of harvest energy from ambient sources enables the lifetime of battery-operated for wearable devices. The human body is a constant heat source, and typically a temperature difference exists between body skin and the environment. Even in a scenario where the wearer located in a dark room or stationary or presence in air condition room, energy can be produced. Because the thermoelectric generates electrical power from heat flow across a temperature gradient, and it is based on the solid-state technology with the principle of Seebeck effect. As the heat flows from hot to cold, free charge carriers (electrons and holes) in the material are driven, and the resultant voltages. Similarly, depending on power generator size, place, and

activity of human body is suitable for harvesting energy in the range of microwatts to hundreds of milliwatts.

The performance of wearable thermoelectric power generator (WTPG) material is closely related to the dimensionless figure-of-merit (zT), $zT=[(S^2\sigma)/\kappa]\ T$, where S represents as thermopower (Seebeck coefficient), σ represent as electrical conductivity, κ represent as thermal conductivity, and T is the temperature respectively. Since the advent of nanostructured power generation materials exhibits high zT owing to the maximization of power factor ($S^2\sigma$) and reduction in κ. Throughout the literature, the nanometer-scaled crystalline structure can reduce κ by enhancing the boundary scattering of phonons, but it degrades the power factor, simultaneously. With the aim of bettering the power factor, an increment of thermopower is expected by tailoring the density of states through nano-structuration such as nanocomposites and superlattices and doping modulation.

Traditional materials for thermoelectric such as bismuth telluride have been studied and utilized commercially for the last half century, but recent advancements in materials selection are one of the principal function of the active thermoelectric device as it determines the reliability of the fabrication regarding technical and economic aspects. Recently, many researcher's efforts have been made to utilize oxide nanomaterials for WTPG applications which may provide environmental stable, mechanical flexibility, and light weight with low cost of manufacturing. In precise, fabric containing oxide metals have shown great promise as P-/ N-type materials with improved transport and UV shielding properties. On the other hand, we have focused on ZnO and rGO nanostructures as a high-efficiency WTPG material because they are non-toxic to skin, inexpensive and easy to obtain and possess attractive electronic properties, which means that they are available for clothing with low-cost fabrication. To our observation, we are reporting about the thermoelectric properties of ZnO and rGO nanostructures coated cotton/ carbon fabric via the solvothermal method for the first time.

In this work, we have shown that enhanced UV shielding of 183.34 and thermoelectric power factor of 22 $\mu W/mK^{2,}$ respectively by ZnO mixed nanostructures on cotton fabric (CF) through solvothermal method. It demonstrated that ZnO with mixed nanorods and nanosheets structure could significantly improve its thermoelectric power factor through lower resistivity and higher Seebeck coefficient. After successfully obtaining mixed nanostructures of ZnO, we investigated Ag- and Sb- in ZnO composite through two-step solvothermal method. In composites lead to a high thermopower value of 471.9 $\mu V/\ K^{-1}$ and enhanced UV shielding with a value of 83.96. we consider that this is mainly due to the growth process of ZnO is disrupted, when the Ag composites are introduced, and the growth process is again favored when enough Ag have recombined with the Zn material which may cause the positive effect on the charge separation efficiency. Then the higher value due to the intergranular crystal structure which plays a significant role in charge transport. To take the benefits from reduced graphene oxide (rGO), i.e., lower thermal conductivity due to oxide deficiency defects and high power factor arising from efficient graphene sheets and therefore, the obtained thermopower value of 32 $\mu V/ K^{-1}$. Lastly, the carbon fabric coated with ZnO different morphology through ultrasonication assisted solvothermal method was about -0.04 ~ 0.054 μV/K and for bare carbon fabric it was found to be about 0.08 μV/K. In addition to the carrier concentration, it is important to note that there was a change of carrier type from P-type to N-type resulting due to the coating of ZnO on carbon fabric. We understand that these values can be further improved by optimizing composite and improving the surface texture of the carbon fabric.