Interface design for development of high performance thermoelectric film

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Thermoelectric (TE) films, which convert heat to electricity, are attracting considerable attention as one of the sustainable energy power sources [1]. The TE performance at temperature T is quantified by dimensionless figure-of-merit ZT; $ZT=S^2\sigma T/\kappa$, where S is Seebeck coefficient, σ is electrical conductivity, and κ is thermal conductivity. Unfortunately, the trade-off relationship among three TE parameters has made it difficult to increase ZT. Therefore, the independent control of these parameters has been a dream in TE research field.

To enhance ZT, heavy element-based materials have been mainly utilized because of their intrinsically-low κ and -high σ. However, their toxicity and expensiveness are problematic for industrial use. On the other hand, light element-based materials, which are nontoxic and cost-effective, have low ZT due to high κ. In recent years, the introduction of nanostructure interface enhanced phonon scattering rate, leading to the drastic reduction of κ regardless of element species [2, 3]. However, not only phonon but also carrier is scattered at the nanostructure interface, decreasing σ.

Oxide films such as ZnO, SnO_2, etc., which are nontoxic, cost-effective, and stable in the air, exhibit relatively-high σ. However, their high κ values have been a bottleneck for TE application. Using such oxide films, we developed the interface control technique to reduce κ while keeping high σ. In this talk, we present two topics based on interface design: (1) domain engineering in SnO_2 films [4]; (2) nanowire interface introduction in ZnO films [5].

We show the growth method of SnO_2 films as an example. The SnO_2 films were epitaxially grown on various kinds of substrates (c-Al_2O_3, r-Al_2O_3, and quartz glass) using pulsed laser deposition under the following condition: substrate temperature was 600ºC; substrate-target distance was 50 mm; oxygen pressure was 5 Pa.

The epitaxial SnO_2 films/r-Al_2O_3 exhibited higher σ than other films because of smaller interface defect density. At the same time, κ of the epitaxial SnO_2 films/r-Al_2O_3 was 10 times lower than that of SnO_2 bulk. This is attributed to the enhanced phonon scattering rate at the crystal domain interface. On the other hand, nanowire introduction in ZnO films increased S because of energy filtering effect brought by tuning the interface defect density. This talk will discuss the details about the relationship between interface design and TE properties.

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