Metal-oxide thin films as high efficiency thermoelectric materials

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The continuous quest for advanced technologies and materials towards clean and renewable energy consumption model has triggered a large amount of research activities. In particular, thermoelectricity represents a good example of smart heat management, e.g. the waste heat production from a primary process is converted into usable energy. A large figure-of-merit ($ZT=S^2\sigma/k$) is usually the key parameter to obtain a high thermoelectric efficiency. To achieve this, two strategies are usually followed: i) decreasing the thermal conductivity (k), and 2) Increasing the power factor ($S^2\sigma$; S:Seebeck coefficient, σ:electrical conductivity). While the former is usually achieved by enhancing phonon scattering by nanostructuring [1,2], the later is achieved by modification of the electronic density of states [3]. Metal-oxides present many interesting properties such as their high thermal and chemical stability, which make them ideal candidates for high temperature thermoelectric applications. However, due to the poor electrical conductivity their prospect as thermoelectric materials has been overlooked. Recently, the observation of enhanced electrical conductivity and Seebeck coefficient in layered metal oxide such as $NaCo_2O_4$ and Ca_3CoO_9 [4], has renewed the interest in this type of materials. In this case, a strongly correlated electron layer of CoO_2 serves as the electronic-transport layer and the Na^+ ions act as phonon scatterers limiting the thermal conductivity. These materials lead to a figure of merit ZT as high as 0.8 at 1000K [4], which is comparable to a state-of-the-art thermoelectric such as Bi_2Te_3. Furthermore, the low mobility problem was also recently overcame by Ohta and co-workers[5] by applying the well-established concept of the 2-dimensional electron gas formation to increase the electrical conductivity and the Seebeck coefficient of the oxides.

In this contribution, we will present a comprehensive study of the thermoelectric properties of metal-oxides. We will mainly focus on Nb-doped $SrTiO_3$ thin layers as function of film thickness, temperature, and doping level. Figure 1 shows the thermoelectric characterization of lightly (2%) Nb doped $SrTiO_3$ thin films prepared by pulsed laser deposition as a function of the film thickness. A large enhancement of the Seebeck coefficient as well as the power factor is observed for the thinner films, which arises from the formation of a 2D electron gas at the interface between the $SrTiO_3$ thin film and the $LaAlO_3$ substrate. On the contrary, the thermal conductivity of the layers exhibits a 2 to 3-fold reduction with respect to the bulk values arising from the combined effect of boundary scattering with oxygen deficiency within the layers. Furthermore, the ZT values exhibit a similar behaviour as the power factor with values as high as ZT = 0.625 at 300K for the thinner layers. Finally, figure 1 also displays high-resolution TEM images of the layers. In figure 2 we show the thermoelectric properties for V_2O_5 and ZnO thin layers doped with different metals (Ag, Au, Pt, Cr). In this case the figure of merit of these materials is comparable to that observed for the thicker $SrTiO_3$ samples. A comparison between these materials systems will be presented pointing out their relative advantages as good thermoelectrics for future energy conversion applications.

References

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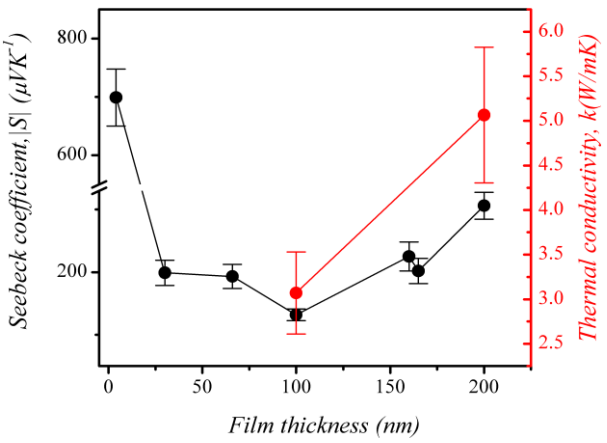

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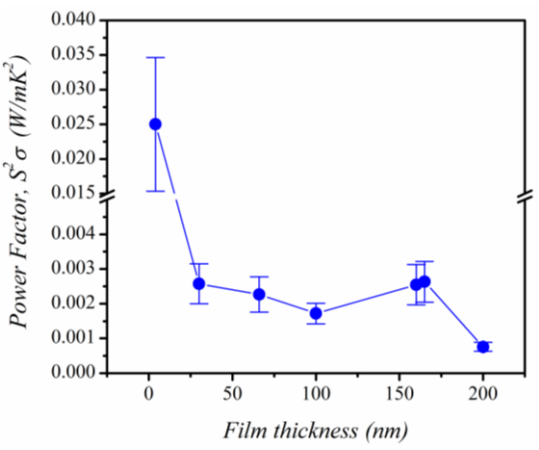

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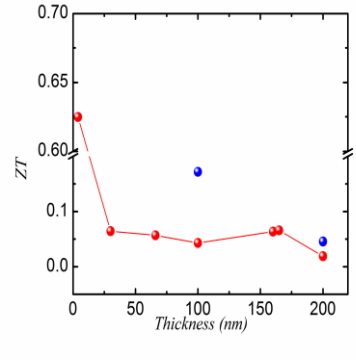

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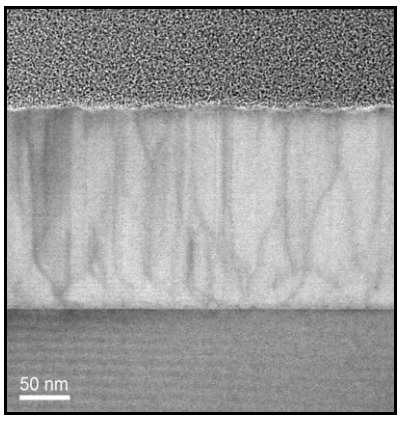

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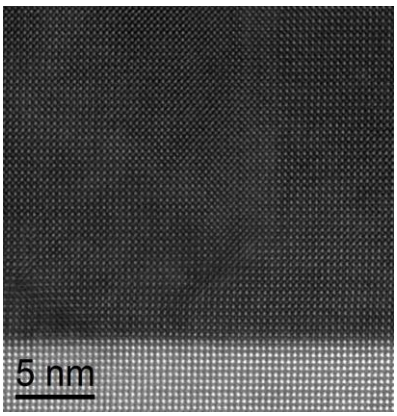

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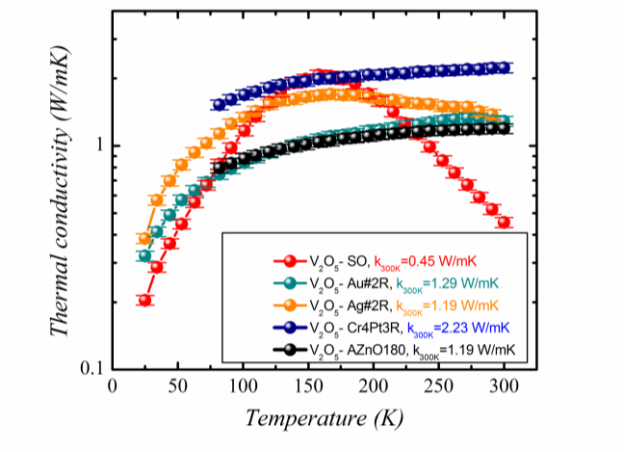
Figure 1: Thermoelectric properties of Nb-doped $SrTiO_3$ thin films on $LaAlO_3$ substrate as a function of the film thickness. *(a)* Seebeck coefficient and thermal conductivity *(b)* Power factor (c*)* ZT (Figure of merit) (d, *e)* High-resolution transmission electron microscopy images of a thin film.



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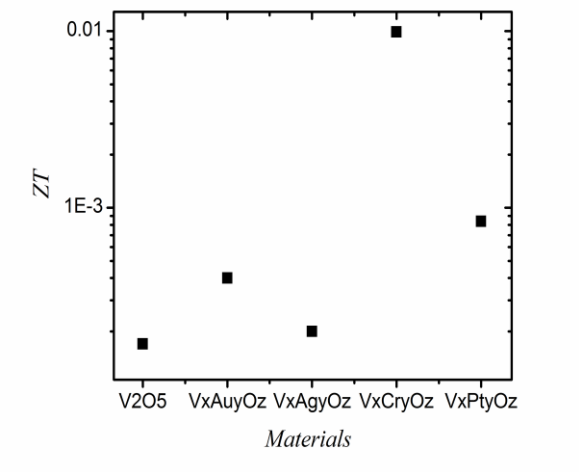

(b)

Figure 2: Thermoelectric properties of V2O5 and ZnO thin flims for different dopants: Au, Ag, Pt, Cr. (a) Temperature dependent thermal conductivity, (b) ZT as a function of the different materials.