Solar Cells Using a Multiferroic Oxide and a Transparent Conducting Oxide

In an atypical marriage of oxides, researchers have succeeded to improve the efficiency of a solar cell using p-type doped lanthanum-bismuth iron oxide (a multiferroic ceramic oxide) and n-type doped indium tin oxide (a transparent conducting oxide).

A multiferroic material exhibits at least two ferroic orders, for example, ferroelectric order and ferromagnetic order. Multiferroic materials are important for making sensors and actuator devices. Since the discovery of enhanced polarization and enhanced magnetization in thin films of hetero-epitaxially constrained perovskite oxide $BiFeO_3$ (BFO),[1] there has been much interest in making piezoelectric or spintronic devices using multiferroic oxides. These studies led to new discoveries; it was soon found that multiferroic materials could also provide a new route to produce electron and hole carriers under illumination,[2] thus showing a potential for making photovoltaic (PV) solar cells using multiferroic-oxide materials.

Combining the properties of multiferroics and multilayer heterostructures, researchers have been working on various possibilities to improve the efficiency of a solar cell. In this article, we highlight a valuable study[3] that uses a modification of perovskite-oxide BFO films to make solar cells. As a solar cell requires a *p*-type (hole-doped) material and a *n*-type (electron-doped) material sandwiched together, the authors used La-doped BFO ($Bi_{1-x}La_xFeO_3$) for the *p*-type and the well known *n*-type transparent conducting oxide (indium-tin oxide, ITO) to make a heterostructure solar cell. In an extensive collaboration between groups from Fu Jen Catholic University, Hwa Hsia University of Technology, Ming Chi University of Technology, Montana State University and NSRRC, the authors, Chi-Shun Tu *et al*., made ceramic films of $Bi_{1-x}La_xFeO_3$ (x = 0.0, 0.05, 0.10 and 0.15; labeled as BFO, BFO5L, BFO10L and BFO15L, respectively in the figures) and undertook careful characterization to establish the *p*-type behavior of $Bi_{1-x}La_xFeO_3$; they then made heterostructures of an ITO film/$Bi_{1-x}La_xFeO_3$ ceramic/Au film for different *x* values, and investigated their PV properties.

The authors used various techniques – micro-Raman spectroscopy, X-ray diffraction, electron microscopy, optical spectroscopy, K-edge X-ray absorption near edge structure (XANES), K-edge X-ray absorption fine structure (EXAFS) and L-edge X-ray absorption spectroscopy (XAS), to characterize $Bi_{1-x}La_xFeO_3$ (x = 0.0, 0.05, 0.10 and 0.15) films. **Figure 1** shows important results obtained using XANES, EXAFS and XAS. The

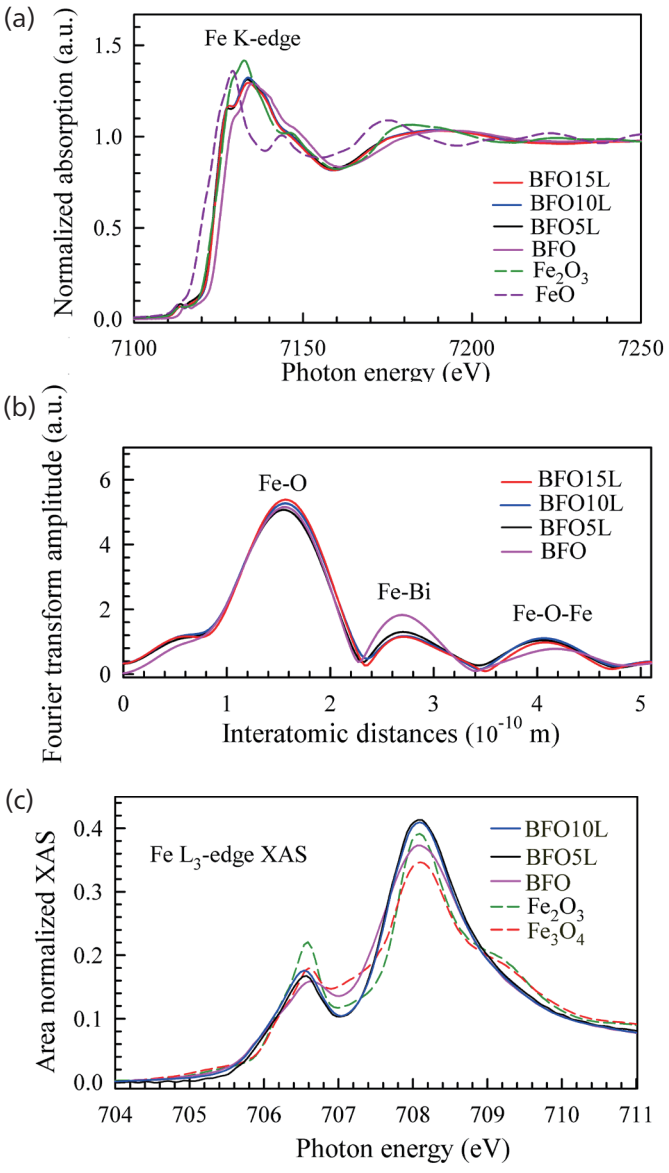

Fig. 1: (a) Fe K-edge XANES spectra vs. photon energy. (b) Fourier transform amplitude of $k^2\chi(k)$ vs. interatomic distance without phase correction. (c) Fe L_3-edge XAS of BFO, BFO5L, BFO10L and reference materials. [Reproduced from Ref. 3]

XANES (**Fig. 1(a)**) and EXAFS (**Fig. 1(b)**) results clearly show that the Fe^{3+} valence, the Fe-O bond-lengths and bond-angles do not change as a function of La content in $Bi_{1-x}La_xFeO_3$. The XAS (**Fig. 1(c)**) results confirm the Fe^{3+} valence for different La-contents in $Bi_{1-x}La_xFeO_3$. These results establish that *p*-type doping in $Bi_{1-x}La_xFeO_3$ is not due to an altered Fe oxidation state but is due to oxygen vacancies. These results correlate also with the smaller band gaps, 2.2 eV-2.4 eV, obtained from optical spectroscopy measurements of $Bi_{1-x}La_xFeO_3$. The authors subsequently made heterostructures of an ITO film/$Bi_{1-x}La_xFeO_3$ ceramic/Au film and tested their PV properties. **Figure 2** shows the results of the PV maximal efficiencies of power conversion, n_{max}, as a function of load voltage and at different illuminations for a series of ITO/$Bi_{1-x}La_xFeO_3$/Au heterostructures. Efficiency n_{max} of power conversion reaches a value as high as 0.19% at illumination I ~2 W/m^2 for the case of a heterostructure made using $Bi_{0.85}La_{0.15}FeO_3$. This value is larger than n_{max} achieved in other BFO based heterostructures such as: (a) graphene/polycrystalline BFO/Pt (n_{max} ~0.0025% under white light, ~1000 W/m^2),[4] (b) Au/polycrystalline BFO/Pt (n_{max} ~0.005%),[5] and (c) ITO/$Bi_{0.9}Ca_{0.1}FeO_{2.95}$/Au ($n_{max}$ ~0.007% under illumination at λ = 405 nm).[6] Although these efficiencies are still less than those of commercially available solar cells, the present study is considered to be an important and valuable step in the right direction for the use of multiferroic heterostructures as solar cells. It is hoped that future work will lead to further improvement in efficiencies of multiferroic-oxide-based heterostructure solar cells. (Reported by Ashish Chainani)

This report features the work of Chi-Shun Tu and his co-workers published in J. Am. Ceram. Soc. ***99****, 674 (2016).*

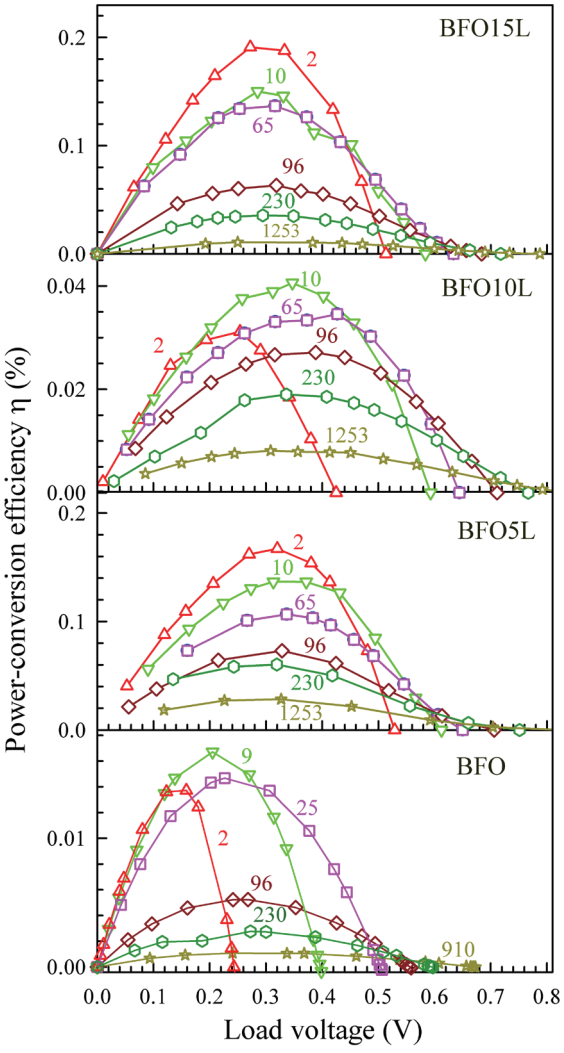

Fig. 2: Power conversion efficiency (η) vs. load voltage. The labeled numbers are illumination intensities in W/m^2. [Reproduced from Ref. 3]

TLS 01C1 SWLS – EXAFS

- XANES, EXAFS
- Materials Science, Condensed-matter Physics

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