Supporting Information

Dielectric enhancement with low dielectric loss in textured ZnO films inserted with NiFe

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Surface morphological properties

It is evident that a NiFe inserted layer has a notable influence on the textured ZnO films dielectric and insulating properties. The enhanced dielectric constant and tunability, together with a lower dielectric loss are achieved in designed ZnO/NiFe/ZnO heterostructured films with optimized layer thickness of inserted NiFe. Thin ZnO/NiFe/ZnO heterostructured films with 10 nm thick NiFe appear to be excellent potential candidates for tunable device applications, and this most likely is due to the variation in the microstructure. In addition, the observed grain size increase with increasing thickness of NiFe inserted layer was paralleled by an increase in the ZnO/NiFe/ZnO heterostructured films permittivity. The grains size in fraction of textured ZnO films with thickness of 150 nm ranged from 26 to 42 nm, with an average size of 34 ± 8 nm as shown in Figs. **S1**(a) and (e); the grains size in fraction of NiFe inserted layer with thickness of 10 nm ranged from 38 to 58 nm, with an average size of 48 ± 10 nm as shown in Figs. **S1**(b) and (f); the grains size in fraction of NiFe inserted layer with thickness of 20 nm ranged from 29 to 53 nm, with an average size of 41 ± 12 nm as shown in Figs. **S1**(c) and (g): the grains size in fraction of NiFe inserted layer with thickness of 30 nm ranged from 23 to 61 nm, with an average size of 42 ± 19 nm as shown in Figs. **S1**(d) and (h). The observed increase in permittivity at the thicker NiFe inserted layer levels, with its associated increase in grain size, because the volume of polarization is enhanced for large grains with respect to that of small grains, hence our present results display an enhanced value of dielectric constant. The value of dielectric constant is an important consideration that is critical for impedance matching in tunable devices. In the present study, the observed that there is a notable improvement on dielectric properties associated with grain size variation, which maybe affect the heterostructured films dielectric breakdown voltage [1, 2].

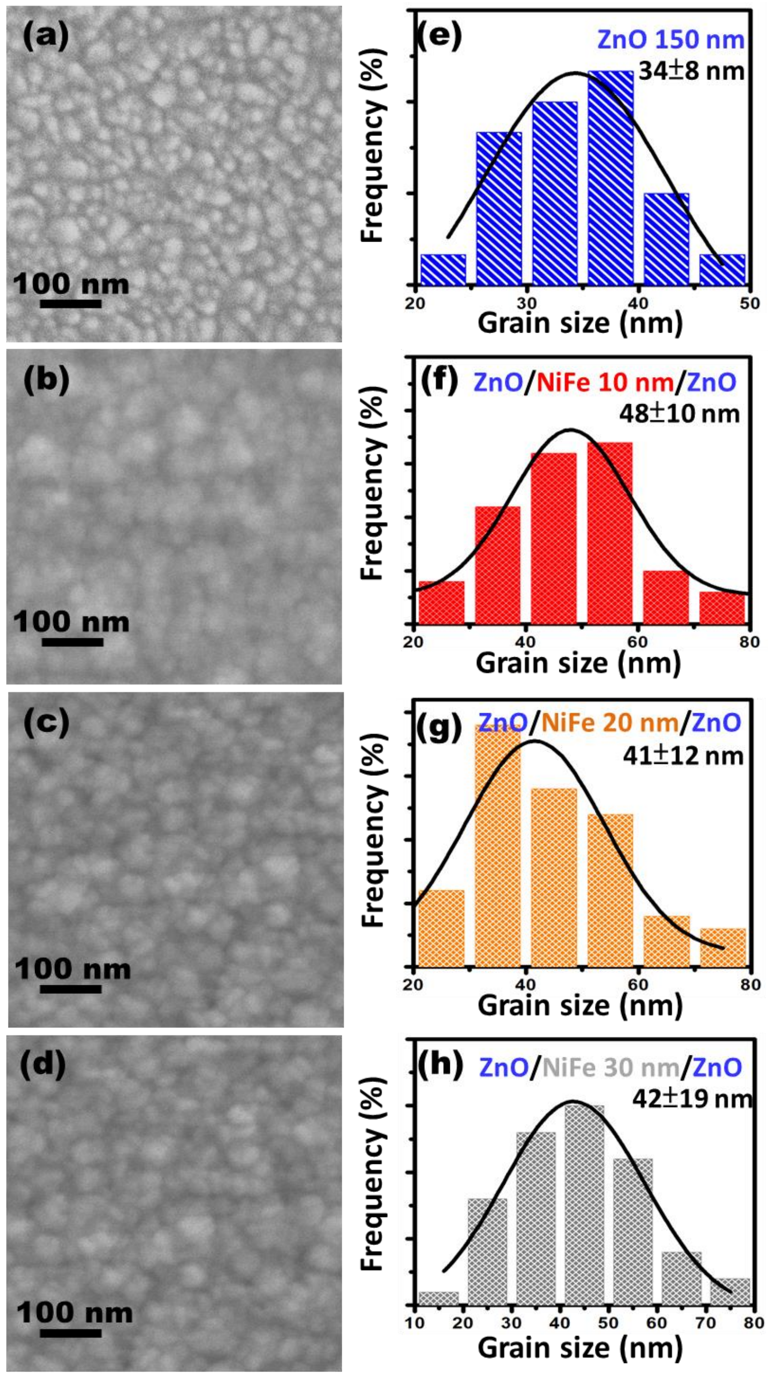

Figure S1. Top view FE-SEM images for the ZnO/NiFe/ZnO heterostructured films inserted with different thicknesses of NiFe layer ranged from (a) 0 nm, (b) 10 nm, (c) 20 nm, (d) 30 nm, respectively. (e)-(h) show the corresponding grain size histograms for evaluating average size and its distribution.

Defects study by PL spectrum

In order to confirm the structural-defect-related dielectric properties, the UV transition and visible emission band were measured using PL spectroscopy at room temperature as shown in Fig. **S2**. The excitation wavelength was the 325 nm (3.82 eV) line of a He-Cd laser with a 2400 grooves/mm grating in the backscattering geometry. One is in UV region, named as near-band-edge (NBE) emission, which is attributed to the recombination of free-exciton. The other one is in visible region, named as deep-level (DL) emission, which is formed by the impurities and various defects in the film such as zinc interstitials and oxygen vacancies [3]. The pure textured ZnO film exhibits a remarkable near-band-edge emission peak located at around 374 nm with a bandgap of 3.31 eV. The ZnO/NiFe/ZnO heterostructured films with relatively board and strong DL emission is presumably attributed to the designed defects between ZnO and NiFe layers, leading to plenty of defects and impurities in the interfacial regions for the formation of numerous dipole moments as shown in the inset of Fig. **S2**.

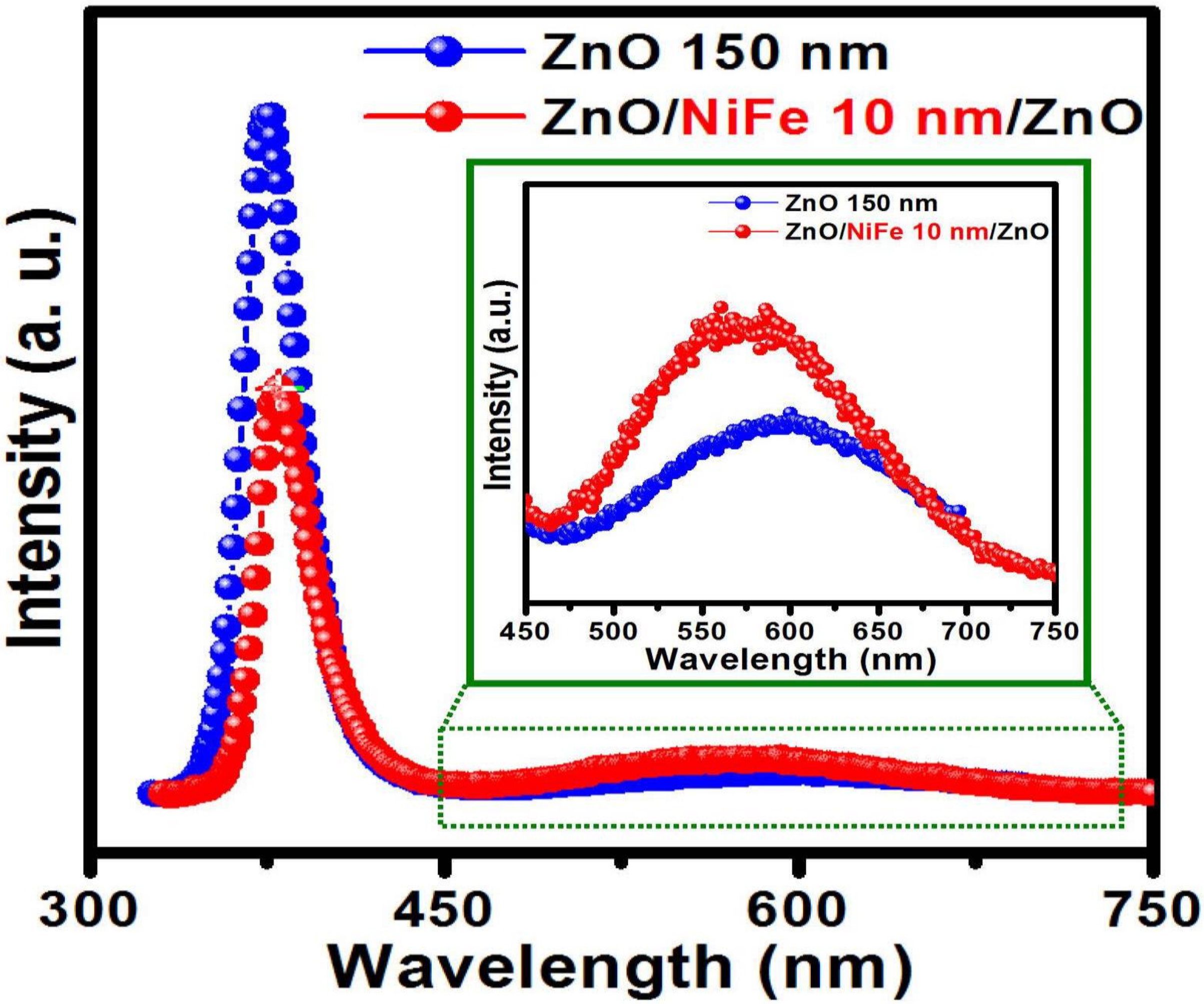

Figure S2. Photoluminescence spectra for the ZnO/NiFe/ZnO heterostructured films without and inserted with a 10 nm thick NiFe layer, respectively.

Optical property of ZnO/NiFe/ZnO heterostructured films

Fig. S3 shows the transparency for the ZnO/NiFe/ZnO heterostructured films deposited onto glass substrates at room temperature with different thicknesses of NiFe inserting layer ranged from 10 to 30 nm, respectively. For understanding the quantitative evaluation of transparency, the average optical transmittance (T_{avg}) is used to estimate the optical property of the thin films deposited onto glass substrates. The equation formula to calculate T_{avg} can be written as:

$$T_{avg} = \frac{1}{\lambda_1 - \lambda_2} \int_{\lambda_1}^{\lambda_2} T(\lambda)\, d\lambda \qquad (1)$$

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where $T(\lambda)$ is the transmittance of the thin films deposited onto glass substrates, and λ_1 and λ_2 are the boundary condition of lower limit and upper limit in wavelengths of the optical measurement. As described earlier, T_{avg} was calculated using Eq. (1) over the wavelength range from 400 to 700 nm. From the transmittance spectrum, it can be clearly observed that the pure ZnO thin film has good transparency and with a visible light averaged transmittance value over 80%. On the other hand, The average optical transmittances of ZnO/NiFe/ZnO heterostructured films with different thicknesses of NiFe inserting layer ranged from 10 to 30 nm are 50 %, 26 % and 15 %, respectively. Obviously, the values of averaged transmittance in a visible light decreased with increasing thicknesses of NiFe inserting layer.

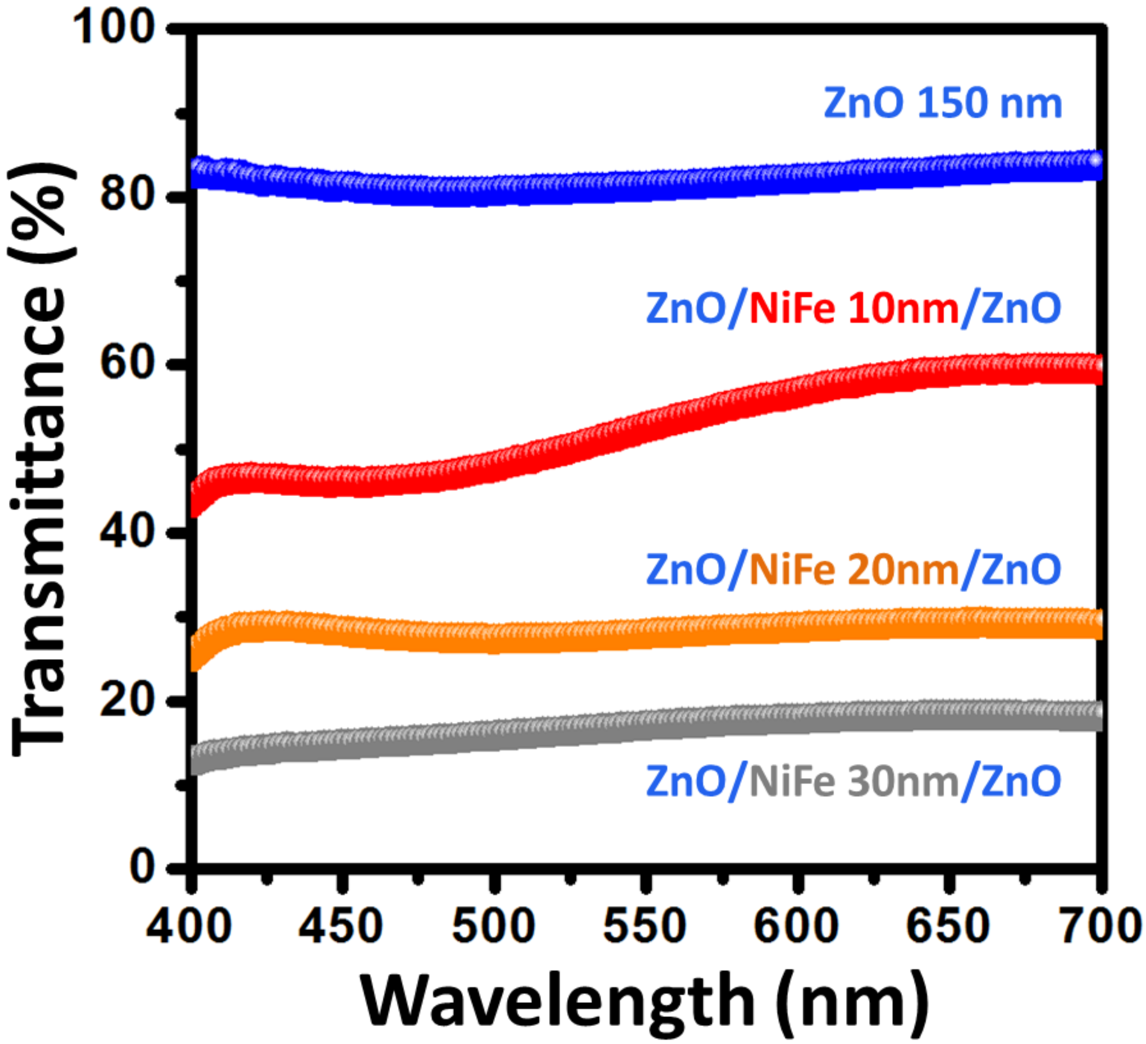

Figure S3. Optical transmittance spectra for ZnO/NiFe/ZnO heterostructured films with various thicknesses of NiFe inserting layer ranged from 0 to 30 nm, respectively.

Reference

[1] L. H. Parker and A. F. Tasch, *IEEE Circuits Devices Mag*. **6**, 17 (1990).

[2] M. W. Cole, W. D. Nothwang, C. Hubbard, E. Ngo, and M. Ervin, *J. Appl. Phys.* **93**, 9218 (2003).

[3] F. K. Shan, G. X. Liu, W. J. Lee, G. H. Lee, I. S. Kim, and B. C. Shin, *Appl. Phys. Lett.* **86**, 221910 (2005).