Growth of epitaxial $CoFe_2O_4$/PZT hetero-structures and ferroelectric-ferromagnetic characterization

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Abstract

In this work we report the epitaxial growth of $CoFe_2O_4$ (CFO) and Lead Zirconium Titanate (PZT) heterostructures using a pulsed laser ablation process with favorable conditions for epitaxial growth of thin films. These structures have been deposited on MgO (100) that has a close lattice match with both CFO and PZT. $CoFe_2O_4$ has one of the highest magnetostrictive coefficients among ferrites while PZT possesses a high piezoelectric coefficient. The possible coupling between the magnetic moment and the electrical polarization in these structures is mediated by the interfacial stress is of great interest for multiferroic devices. The epitaxial relationship between the CFO and PZT films are important to maximize the elastic interaction at the interface. Epitaxial relationship has been confirmed by the Θ-2Θ and Φ x-ray diffraction scans. The 0.1° width of the CFO(400)-PZT(200) x-ray diffraction peak measured by the rocking-curve method also indicates a high degree of epitaxy. AFM scans have been performed to measure the surface roughness of the thin films. The magnetic and electric measurements of these films and the correlation between these measurements and the structural parameters are presented.

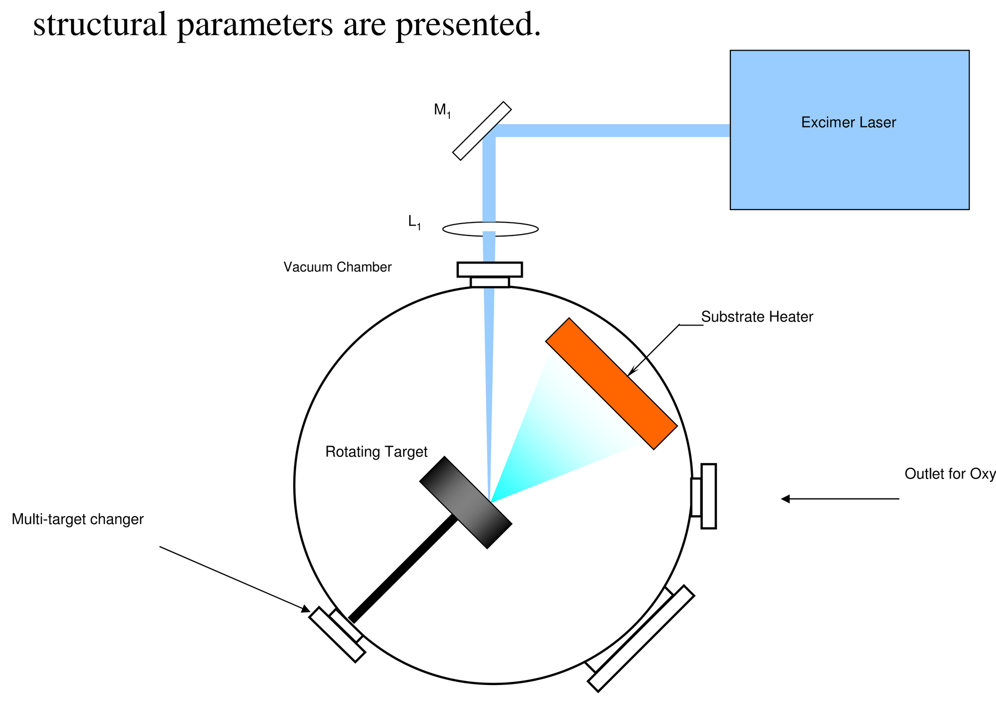
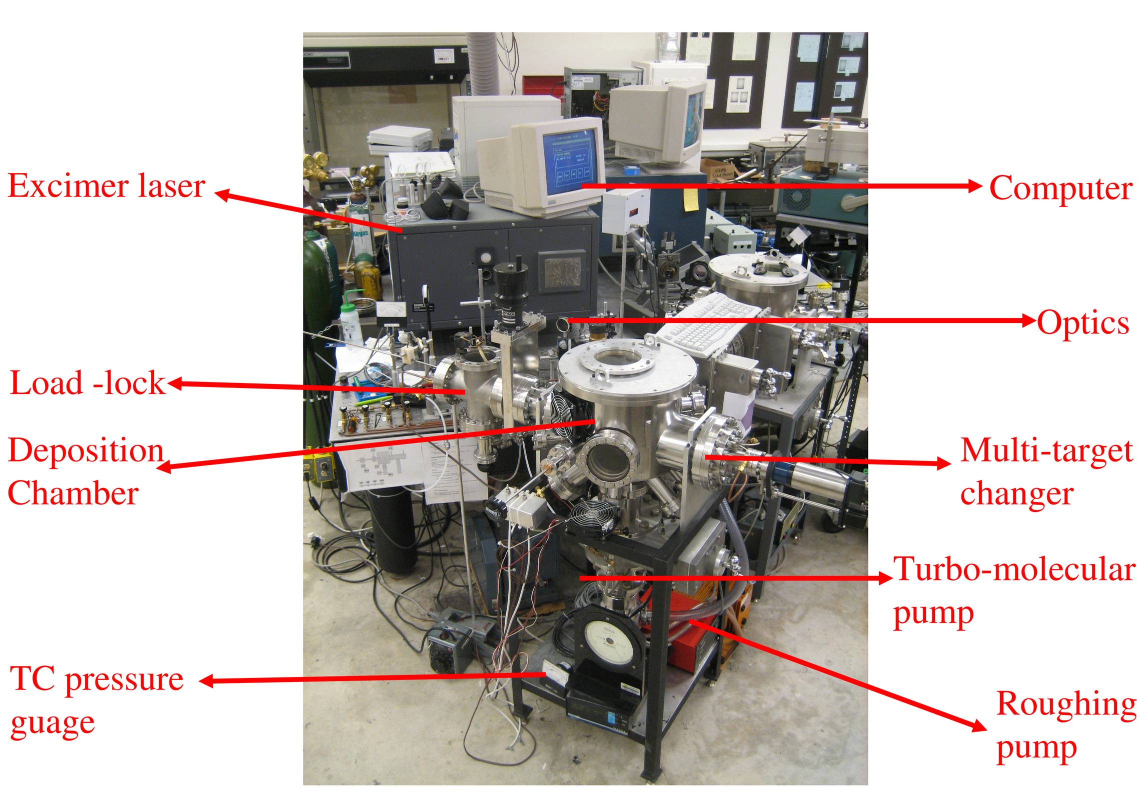


Diagram of the pulsed single laser deposition system

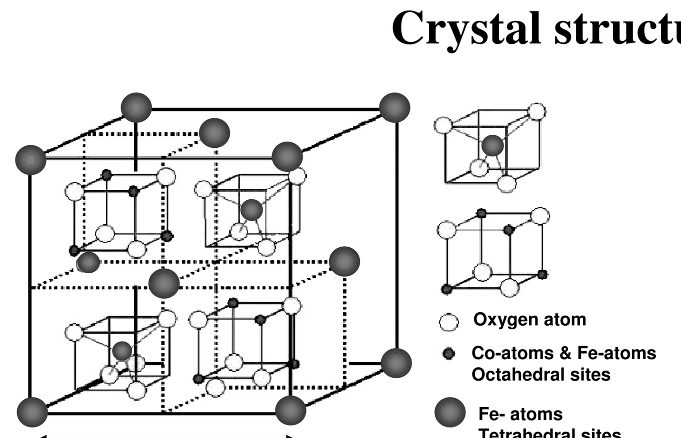
Benefits of PLD:

- produces films with composition typically identical to that of the target
- highly forward-directed and confined plume of highly energetic materials which have sufficient ion mobility for the growth of epitaxial thin films
- multilayer materials can be deposited in situ.

Laser wavelength: 248 nm
Pulse width: ~ 20 ns
Laser energy: ~ 154 mJ
Spot size at the target: ~ 0.06 cm^2
Background Pressure: ~ 10^{-7} Torr
Substrate-to-target distance: 6 cm
Fluence at target ~ 2 J/cm^2

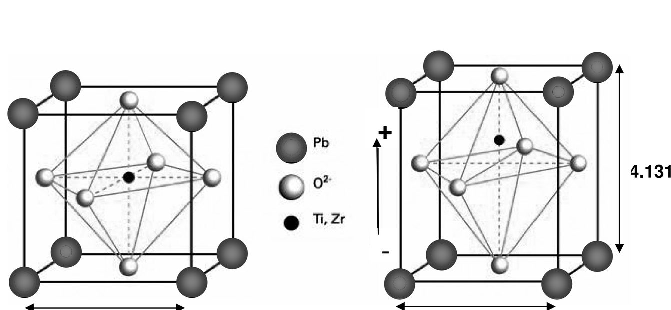


Crystal structures



Cobalt Ferrite: CoO-Fe_2O_3

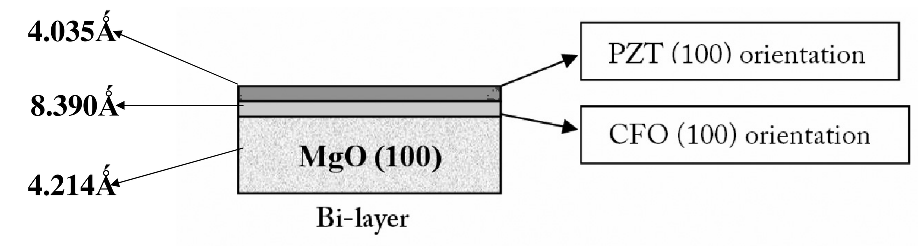
- face centered cubic with lattice constant a = 8.390 Å

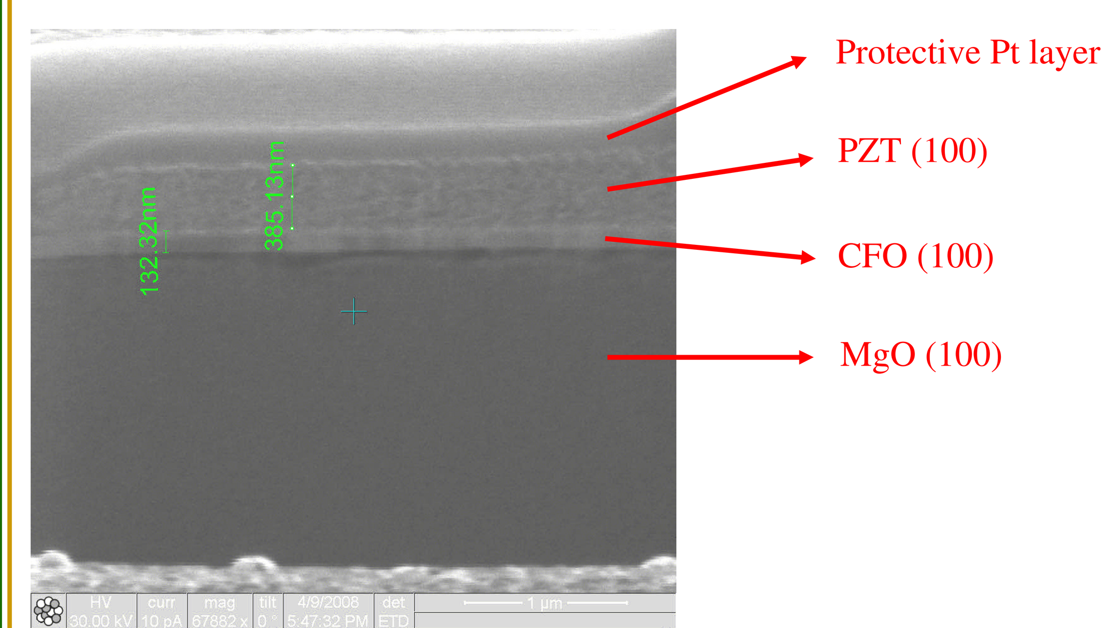


Lead Zirconium Titanium Oxide (PZT): $PbZr_xTi_{1-x}O_3$

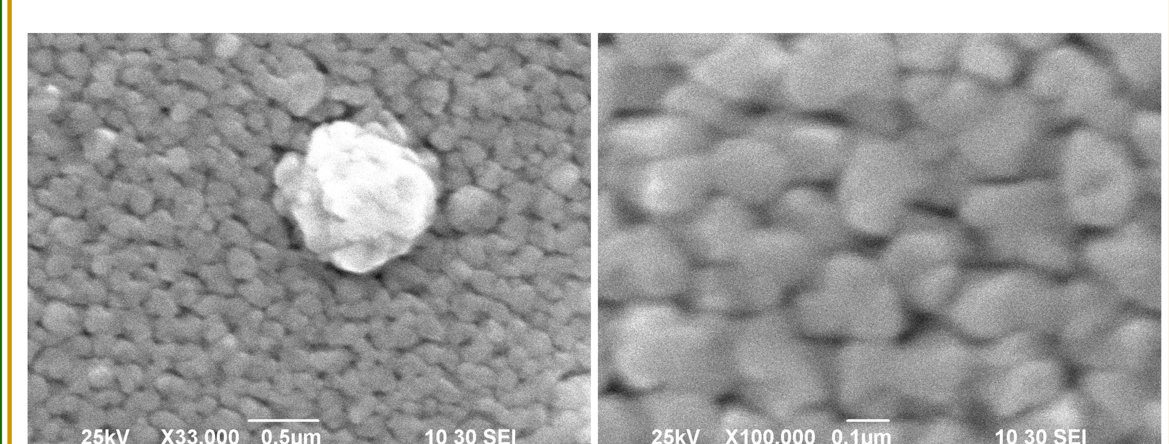
- above T_{Curie} cubic with lattice constant a = 4.035 Å
- below T_{Curie} perovskite (tetragonal) ith lattice constant a = 4.035 Å and c =4.131Å

$CoFe_2O_4$-PZT heterostructure





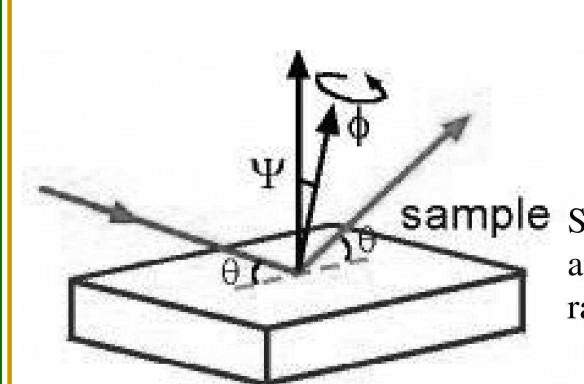
Focused Ion Beam image of CFO-PZT bilayer on MgO substrate



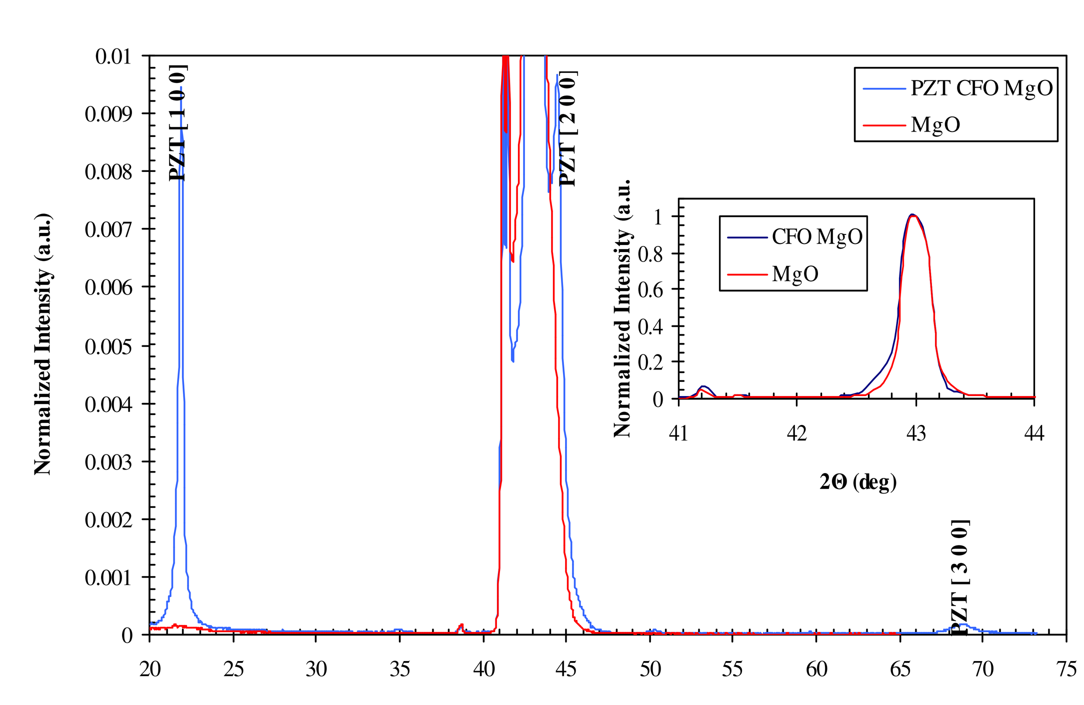
SEM images of CFO-PZT bilayer film on Si substrate

SEM images show that the grain sizes are approximately 100 nm on conducting Si substrates. Since PZT is an insulating material it was difficult to obtain high resolution SEM images of CFO-PZT bilayer on MgO substrate.

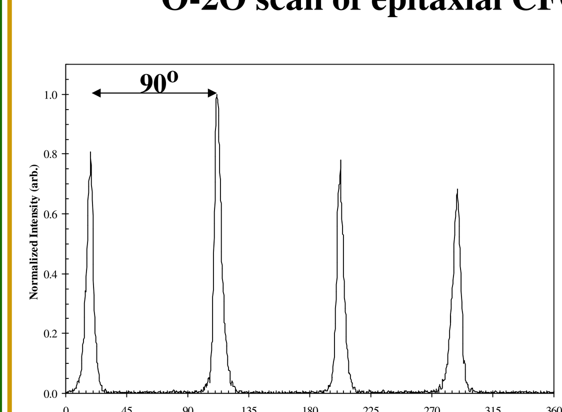
XRD measurements



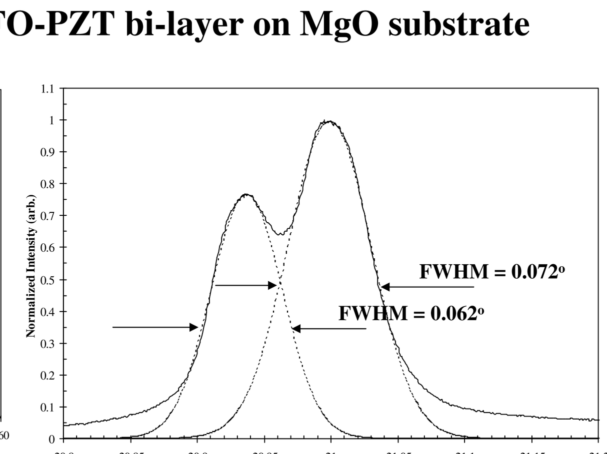
Schematic diagram showing the Θ, Φ, ψ angles with respect to the sample and X-ray beam.



Θ-2Θ scan of epitaxial CFO-PZT bi-layer on MgO substrate



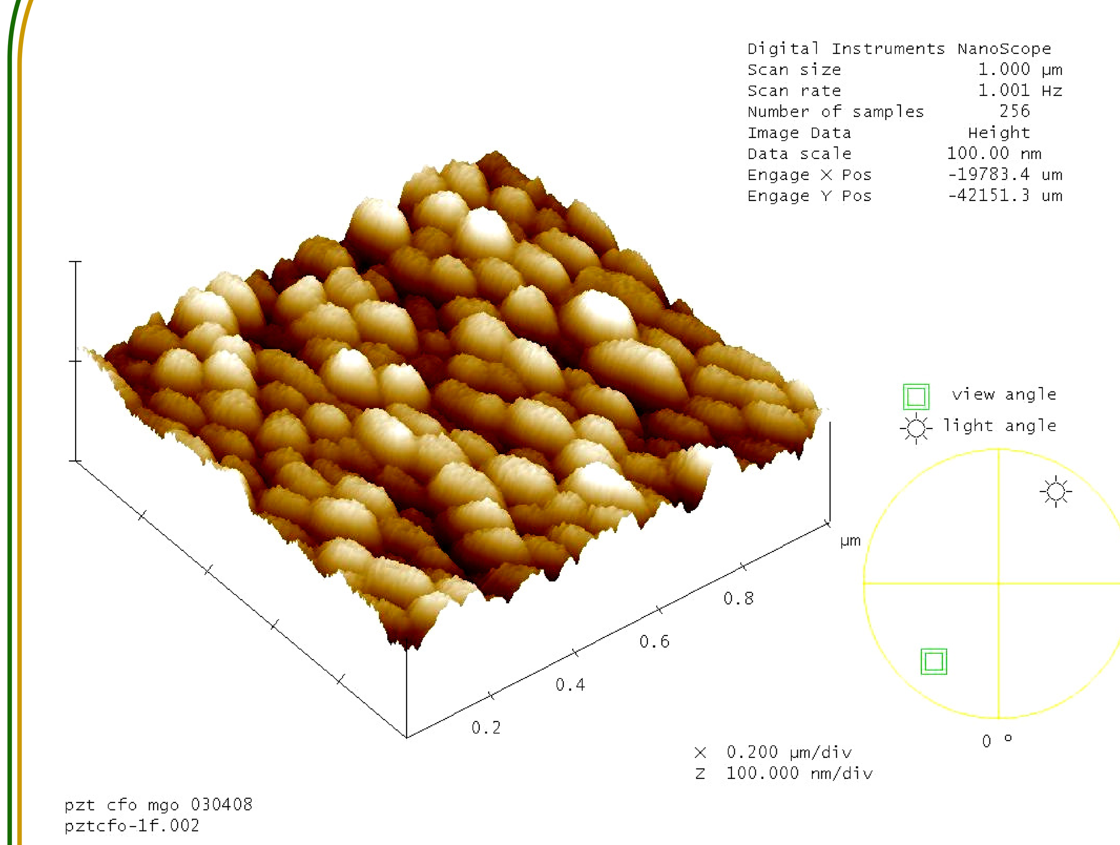
Φ scans CFO-PZT bilayer thin film deposited on MgO [1 0 0] substrate. The Bragg plane chosen for refection is [101] plane as it give the highest peak in powder.



Rocking curve (ω-scan) of CFO(400)-PZT(200) peak showing a large degree of planar orientation [FWHM of CFO(400) peak is 0.062° at Θ = 20.93° and FWHM of PZT(200) peak is 0.072° at Θ = 20.99°]

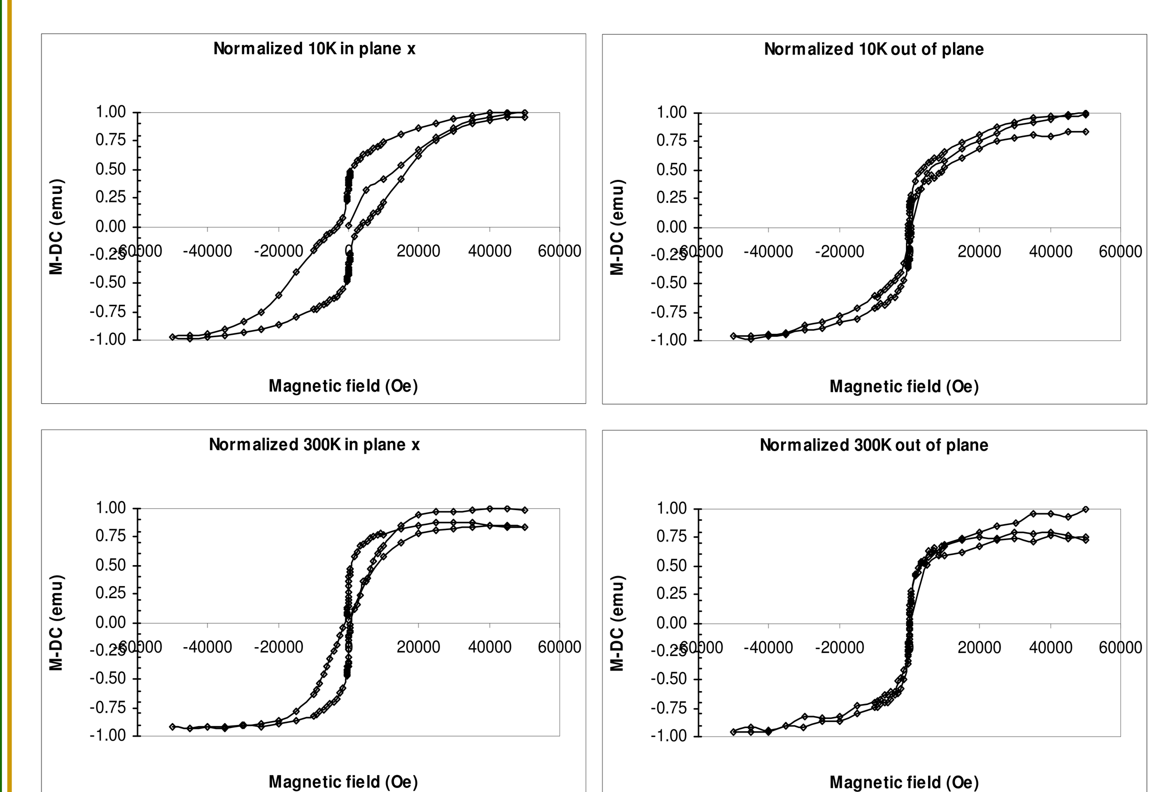
XRD analysis confirms the epitaxial relationship between the substrate and bi-layer thin film and between the bi-layers.

Surface roughness measurement



AFM image showing 3 dimensional projection of surface topography. The film thickness is 200nm. Scan area 1μm x 1μm. The RMS value for surface roughness is 9.967nm. This is very small compared to film thickness.

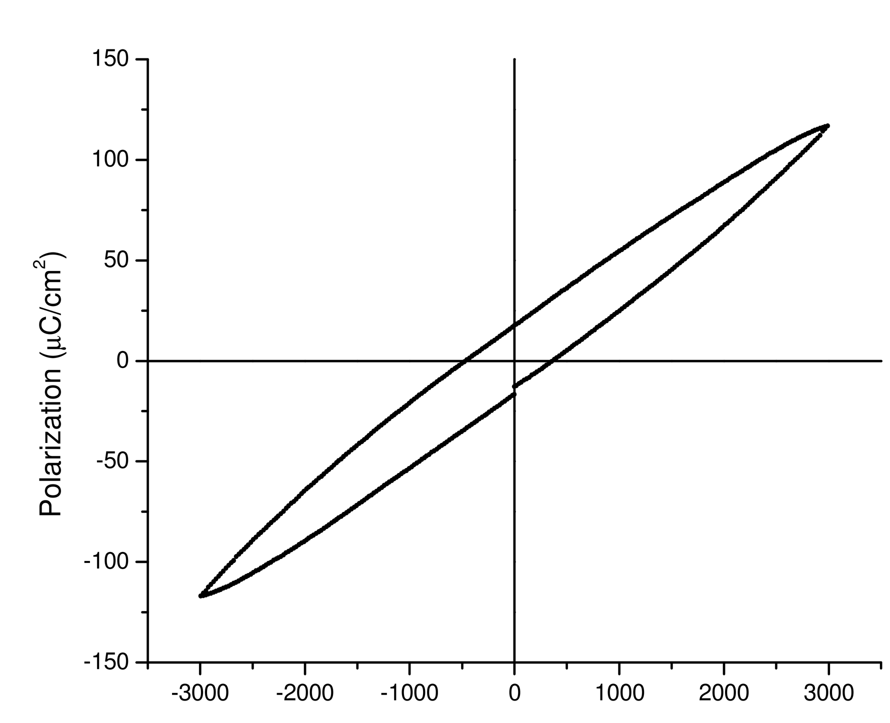
Magnetic measurement



M vs H hysteresis loops of CFO-PZT (200nm-200nm) epitaxial bilayer on MgO substrate using PPMS measurements

Magnetic measurements show that the coercive length is larger when the magnetic field is applied in plane than when it is applied out of plane. Thus the magnetic easy axis is out of plane.

Polarization measurement



P vs E hysteresis loops of CFO-PZT (200nm-200nm) epitaxial bilayer on MgO substrate using Precision LC Ferro-tester

Polarization curve shows typical characteristics of a combination of ferro-electric material (PZT) and a dielectric material (MgO).

Conclusion

1. Growth of CFO-PZT epitaxial bilayer thin film on MgO substrates using PLD.
2. Confirmation of epitaxial growth through XRD analysis using Θ-2Θ scans, Φ scans and rocking curve technique.
3. Grain size and surface roughness measurements using SEM and AFM scans.
4. Magnetic properties through M vs H hysteresis loop measurements using PPMS.
5. Electrical polarization through P vs E hysteresis loop measurement using Precision LC Ferro-tester.

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