A Novel Nanowire-Based Magnetoelectric Oxide Heterostructure

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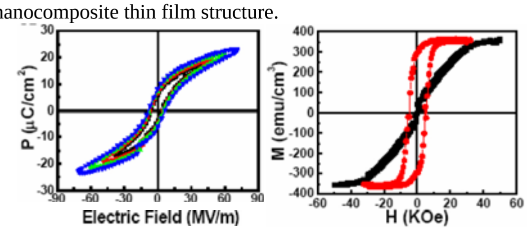
ABSTRACT

- The magnetoelectric effect is defined as the variation of the dielectric polarization response under an applied magnetic field, or the presence of an induced magnetization under an external electric. For example, in a multiferroic system which is both ferroelectric and ferromagnetic, one can control the electric polarization with an applied magnetic field and the magnetic properties with an applied electric field.
- In this project, nanostructured multiferroic nanowires will be synthesized and their properties investigated. The pulsed laser deposition technique will be employed to deposit a ferroelectric-ferromagnetic composite heterostructure encapsulating a MgO nanowire template synthesized by chemical vapor deposition. E-beam lithography will be used pattern interconnects to the nanowires for magneto-electric characterization.
- Multiferroic nanowires are attractive for a host of next-generation applications, including miniaturized magneto-electric memory, magnetic field sensors, electrically controlled magnetic devices, and magnetically controlled piezoelectric devices.

What is Multiferroic?

- The coupling of magnetic, electronic and shape altering properties, referred to as the magneto-electric effect, allows for dual functionality in a single-phase or composite material system. The plots below show the ferroelectric and ferromagnetic hysteresis observed in a multiferroic $BaTiO_3/CoFe_2O_4$ 3-dimensional (3D) nanocomposite thin film structure.



(a) Ferroelectricity (b) Ferromagnetism

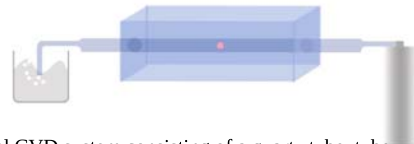
(a) Polarization - electric field hysteresis loop showing that the film is ferroelectric with a saturation polarization $P_s \sim 23$ C/cm².
(b) Out-of-plane (red) and in-plane (black) magnetic hysteresis loops depicting the large uniaxial anisotropy.

*Reference : H. Zhong, and R. Ramesh, et al. Science **303**, 661 (2004).*

Why Nanowire-Based Multiferroic Structures?

- The magnetoelectric effect in a multiferroic thin film bilayer is substantially reduced due to clamping effect of the substrate.
- A nanowires template can minimize the clamping effect.
- Further, by etching away the template material (e.g. MgO), an unclampled nanotube geometry can be fabricated, which is expected to exhibit enhanced magnetoelectric effect .

Chemical Vapor Deposition (CVD) System

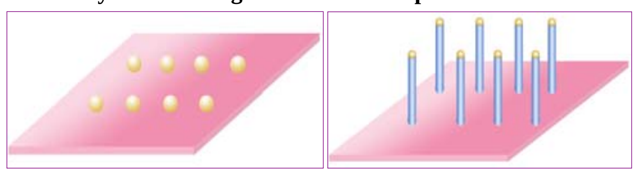


- Traditional CVD system consisting of a quartz tube, tube furnace, precursor, oxygen and argon gases, and water bubbler.

Synthesis of magnetoelectric nanostructures

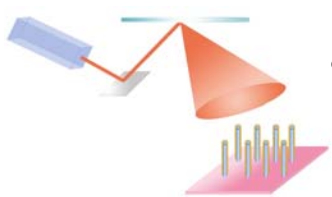
- A novel nanowire-based magnetoelectric heterostructure for device applications will be developed using a combination of:

▪ CVD Synthesis of MgO Nanowire Template



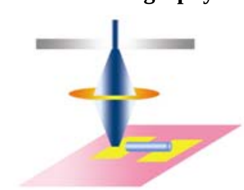
- Thin gold film catalyst (1-2 nm) is deposited by e-beam evaporation on MgO substrate. Nano gold dots are formed at high temperatures (900-950ºC).
- MgO nanowires are synthesized by vapor-liquid-solid (VLS) mechanism using Mg_3N_2 precursor.

▪ Pulsed Laser Deposition (PLD) of Ferroelectric-Ferromagnetic Heterostructures



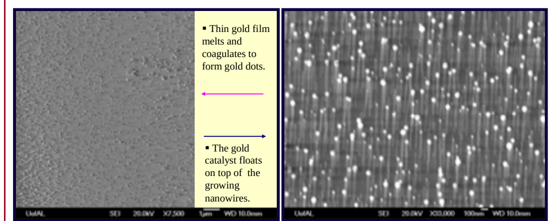
- Multiferroic heterostructure deposited on MgO nanowires
  – $BaTiO_3$ ferroelectric layer
  – $CoFe_2O_4$ (or $NiFe_2O_4$) ferromagnetic layer.

▪ E-beam Lithography for Depositing Contacts

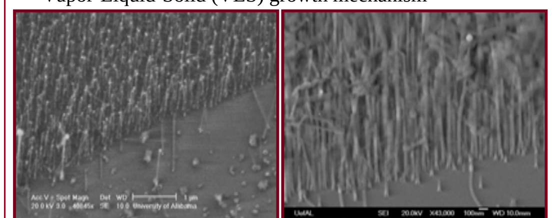


- JEOL SEM for e-beam lithography.
- Contact electrodes deposited by liftoff.

SEM Images of MgO nanowires



- Vapor-Liquid-Solid (VLS) growth mechanism



- High density of MgO nanowires grown using Au catalyst

- Dispersed nanowire for e-beam lithography patterning

Future Plans

- Use PLD for the growth of ferroelectric-ferromagnetic layers and e-beam lithography for fabricating contacts.
- Magnetoelectric nanostructures will be characterized using HRTEM and atom probe.
- Electrical, magnetic and magnetoelectric characterization of the nanowire-based heterostructures.

Conclusion

- Vertically aligned MgO nanowires have been successfully synthesized by CVD through VLS mechanism.
- PLD technique will be employed to deposit coupled ferroelectric-ferromagnetic bilayers.
- Development of an e-beam lithography process for fabricating contacts is in progress.