Transfer of Ferroelectric Films Using Laser Exfoliation Process

Sergio Rocha[1], Ajay Yadav[2] and Sayeef Salahuddin[2]

[1]Cabrillo College

[2]Department of Electrical Engineering and Computer Science, University of California, Berkeley

2017 Transfer-to-Excellence Research Experiences for Undergraduates Program (TTE REU Program)

Abstract

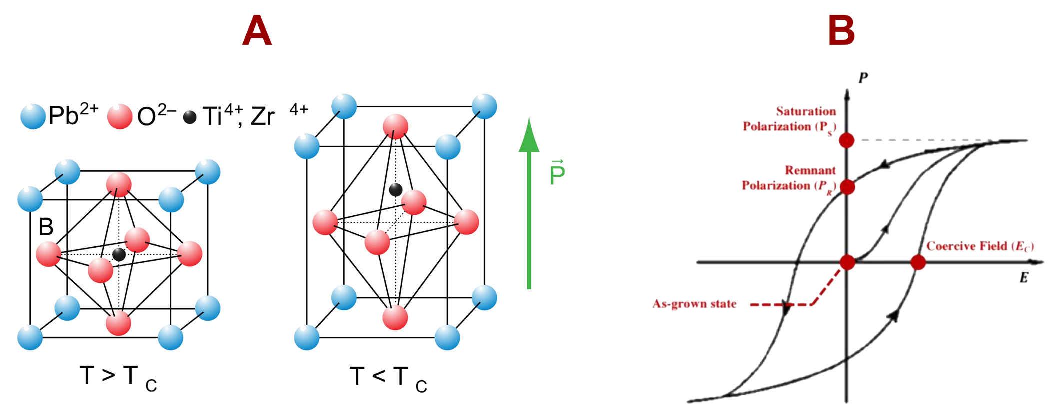
Improving fabrication methods of transistors has been an area of interest for the integration of ferroelectric materials onto silicon. Incorporating ferroelectric materials into the oxide layer of transistors could potentially open up the path to extremely low-energy electronics. Directly depositing a ferroelectric material like lead zirconate titanate (PZT) onto silicon (Si) poses a challenge due to several factors. In order to circumvent such challenges, we attempt a novel transfer method of laser exfoliation. Standard methods, such as pulsed laser deposition (PLD), were used to deposit PZT on lanthanum strontium manganite (LSMO) on strontium titanate (STO). Using laser light of wavelength 532 nm we can ablate LSMO successfully. Having a transparent layer such as polymethyl methacrylate (PMMA, which can also be used a transfer layer) on top of PZT is then deposited using spin coating method. This whole stack of PMMA/PZT/LSMO/STO was then subjected to laser exposure, which removes LSMO from the substrate STO, leaving behind the PZT on PMMA. This PZT on PMMA can later be transferred onto any substrate such as silicon. By using X-ray diffraction (XRD) we ensure that the materials (PZT, LMSO, and PMMA) have not undergone any undesired changes in any of the processes' steps.

Motivation

- Functional oxides have shown a plethora of properties, such as ferroelectricity (an example of ferroelectric oxide *i.e.* $Pb_{0.8}Zr_{0.2}TiO_3$ (PZT) is shown in Fig 1) [1]. Active research is underway to integrate such functional oxides directly on Silicon to improve and/or overcome current issues, such as memory retention time of Ferroelectric Random Access Memories (FeRAMs) [1].

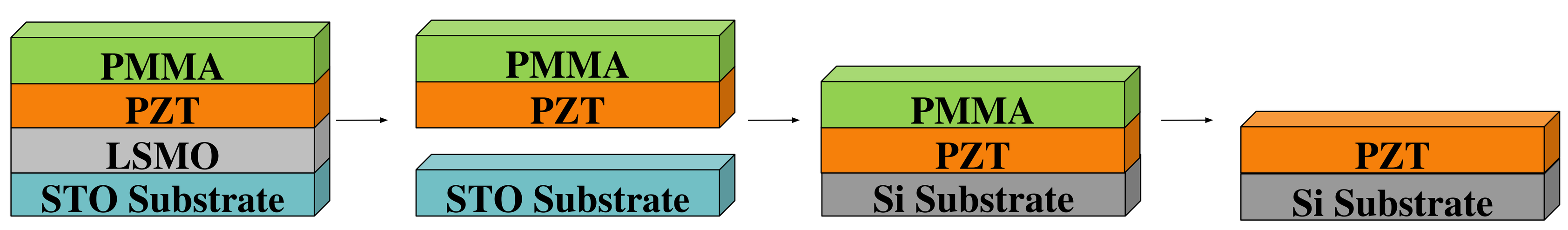
- In literature, there has been reports of transferring PZT onto Silicon using LSMO as the sacrificial layer and wet etching of LSMO as the main step [2]. Due to the slow etching of LSMO, other methods are actively being searched to transfer PZT faster and more efficiently. In this research, we have used laser ablation of LSMO as the main step to remove LSMO from the STO and transfer PZT onto to a desired substrate like Silicon.

Fig. 1 (A) Crystal structural of PZT before and after ferroelectric phase transition; (B) Polarization vs. Electric Field showing a hysteresis loop for a standard ferroelectric material.



Goal / Transfer Process

- Transfer PZT onto Silicon (Si)
  - Challenging to directly deposit PZT onto Si due to several factors (such as crystal chemistry or mechanical incompatibility)

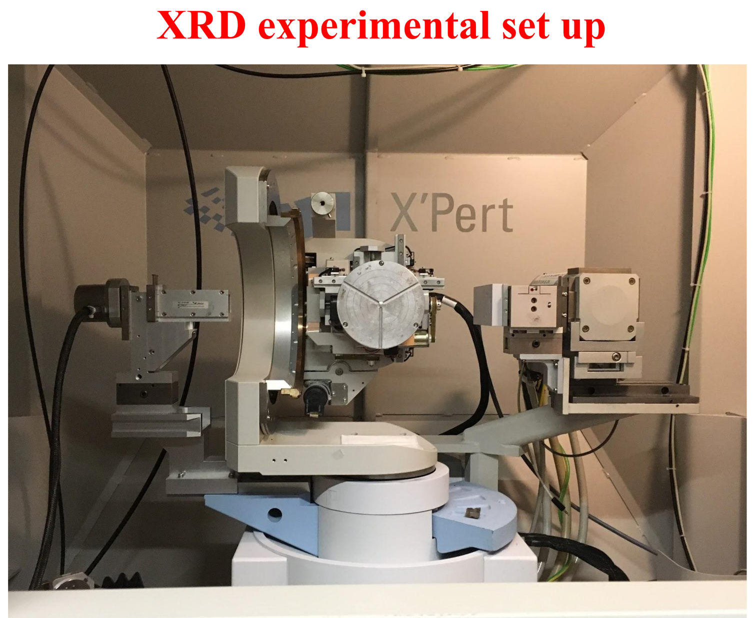


Methods

- **Pulsed Laser Deposition**
  - LSMO Growth
    - Temp: 750℃
    - Pressure: 100 mTorr
    - Energy Density: 1.0 J/cm^2
    - 2 Hz
  - PZT Growth
    - Temp: 630℃
    - Pressure: 100 mTorr
    - Energy Density: 1.0 J/cm^2
    - Frequency: 10 Hz
- **Spin Coating Deposition**
  - 10,000 RPM
  - 240 seconds
  - Post-baking at 95℃
- **X-Ray Diffraction (XRD)**
  - XRD can be used to determine crystallinity of a thin film grown on a substrate. It can also be used to determine thickness of a thin film.
- **Laser Exfoliation Parameters**
  - 100 mJ, 1 Hz
  - 2 mm diameter
  - Single Pulse

LASER experimental setup

XRD experimental set up

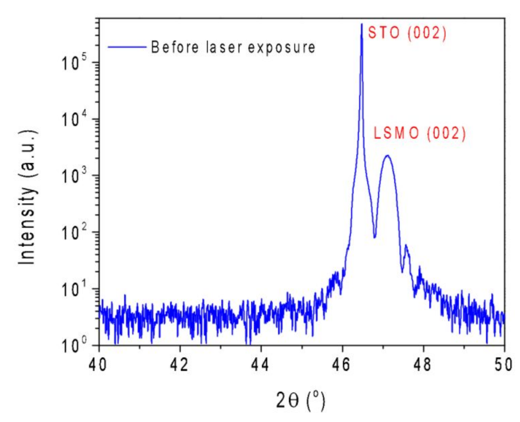


Results & Discussion

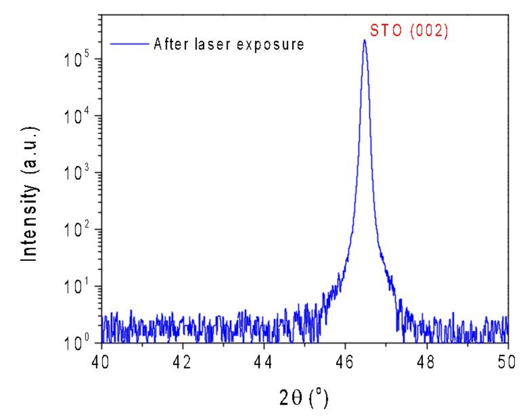
LSMO/STO (001)

As can be seen from the XRD graphs before and after laser exposure, LSMO was removed from STO substrate after the exposure. comparing the before & after XRD graphs that the laser exfoliation process was able to ablate the LSMO layer.

XRD:Before Laser exposure



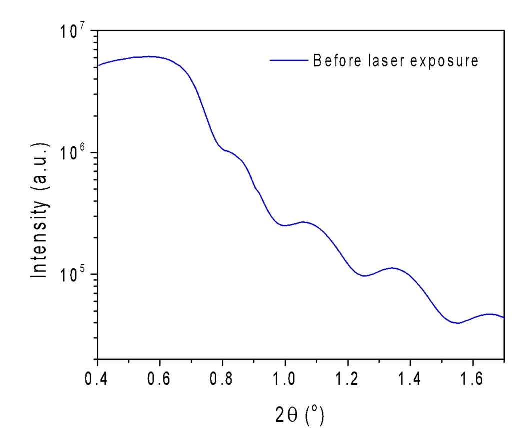
XRD:After Laser exposure



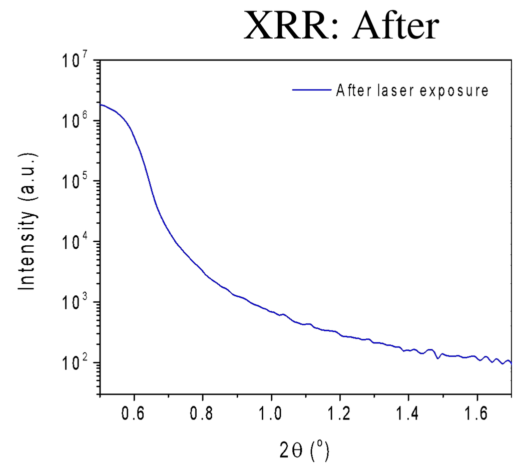
LSMO/STO (001)

The presence of oscillations in XRR scan before laser exposure indicates presence of a thin LSMO film on STO substrate, while absence of oscillations on right suggests LSMO is successfully removed from STO substrate.

XRR: Before



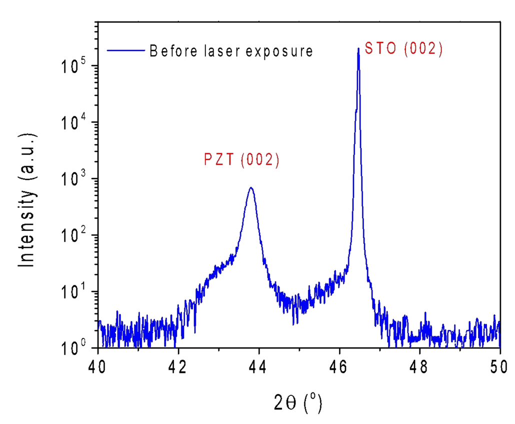
XRR: After



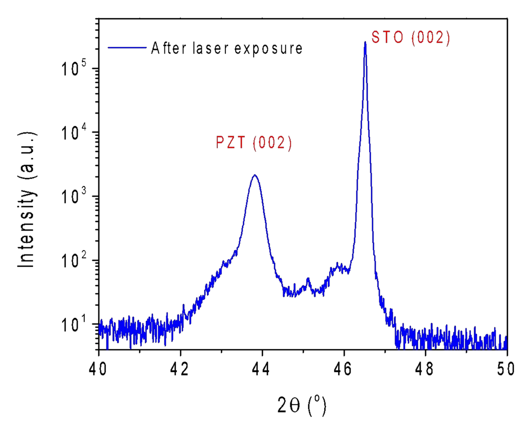
PZT on STO (001)

In this comparison of XRD graphs, we determine whether PZT exposure to laser light of wavelength 532 nm does any harm to film crystallinity. From the result, it is apparent that laser exposure to PZT film does not do any significant changes to film crystallinity.

XRD: Before



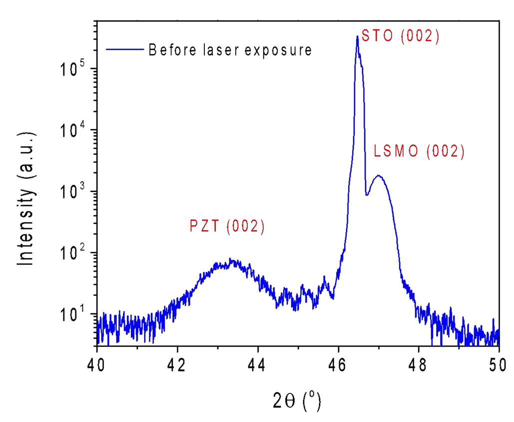
XRR: After



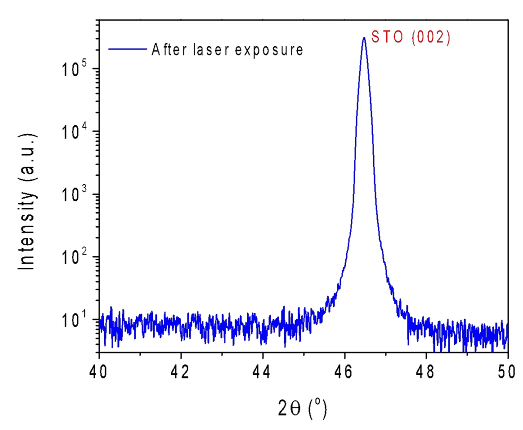
PZT on LSMO on STO (001)

This control experiment was done to show that after laser exposure, due to LSMO ablation, the whole PZT/LSMO stack from top of STO can be removed successfully. It is evident from the result that before exposure XRD shows peaks for both LSMO and PZT, while after exposure only substrate peak is visible.

XRD: Before



XRD: After



Future Work

Future work will include the optimization of each processes to ensure quality of the transferred PZT film remains reasonably good.

References

[1] Bakaul, S. R., Serrao, C. R., Lee, M., Yeung, C. W., Sarker, A., Hsu, S.-L., … Salahuddin, S. (2015). Single Crystal Functional Oxides on Silicon. Nature Communications, 7, 1–5. https://doi.org/10.1038/ncomms10547

[2] Lee, M. Salahuddin, S. (2012). Epitaxial Layer Transfer of Ferroelectric Devices onto Si by Wet Etching.

Contact Information

Sergio Rocha-Fernandez

srocha53@gmail.com

831-840-6614

Funding Support

This work was funded by National Science Foundation Award ECCS-0939514 & ECCS-1461157