PCSI
Room Ballroom South - Session PCSI-4MoA
Oxide Growth and Properties

Moderator: Anders Mikkelsen, Lund University, Sweden

5:15pm **PCSI-4MoA-40 Invited Speaker*, Bharat Jalan,*** University of Minnesota **INVITED**

5:45pm **PCSI-4MoA-46 Strain Enhancement of the Electro-optical Response in Semiconductor-integrated Perovskites*, Alexander Demkov,*** The University of Texas

Interest in perovskite ferroelectrics such a $BaTiO_3$ (BTO) for use in nonlinear optic devices lies in its extremely large electro-optic (Pockels) coefficients >100 pm/V [1]. Even more importantly, the monolithic integration of BTO on semiconductors has paved the way to several types of entirely different devices ranging from ferroelectric memory to electro optical modulators [2-4]. Together, these developments have raised a possibility for applications of BTO in silicon nanophotonics, a hybrid technology combining semiconductor logic with fast broadband optical communications and optical information technologies .

I will discuss the possibility of significantly enhancing the nonlinear electro-optical response in strained perovskite $BaTiO_3$ and $SrTiO_3$ [5]. For $BaTiO_3$, first principles calculations predict the enhancement for both compressive and tensile strain. The physical origin can be traced to strain-induced phonon softening that results in diverging first order susceptibility. Within the Landau-Ginzburg-Devonshire formalism we demonstrate how, in turn, this divergence results in a diverging second order susceptibility and Pockels coefficient. In epitaxially strained $SrTiO_3$ the electro-optical response is calculated for biaxial strain values ranging from -2.0% to 2.0% relative to the theoretically-optimized lattice constant. Under 1.0% tensile strain, the Pockels tensor components that are zero without strain due to the centrosymmetric structure of $SrTiO_3$, increase dramatically. Experimentally, we study the nonlinear optical response in a strained thin film ferroelectric oxide $BaTiO_3$ using piezoelectric PMN-PT as a variable strain substrate and La-doped $SrTiO_3$ as a conductive buffer layer [6]. The rotation-anisotropic second harmonic intensity profile shows hysteretic modulation corresponding to strain variation from the inverse piezoelectric response of the substrate. Our results suggest a promising route to enhance the performance of nonlinear optical oxides for the development of future nano-opto-mechanical devices.

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[2] C. Dubourdieu, et al., Nature Nanotechnology **8**, 748 (2013).

[3] P. Ponath, et al., Nature Comm. **6**, 6067 (2015).

[4] Y. Cho, et al., Appl. Phys. Lett. **112**, 162901 (2018).

[5] K. D. Fredrickson, et al., Phys. Rev. B **98**, 075136 (2018).

[6] K. J. Kormondy, et al., Appl. Phys. Lett. **113** (2018).

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5:50pm **PCSI-4MoA-47 Synthesis of Large Area Single-crystalline Freestanding Oxide Membranes*, Prastuti Singh,*** *A Swartz, D Lu, S Hong,* Stanford University*; K Nishio,* Geballe Laboratory for Advanced Materials*; Y Hikita,* Stanford Institute for Materials and Energy Sciences*; H Hwang,* Stanford University

Recently, a number of 2D materials have been the focus of intense study for the development of nanoelectronics [1]. One potential platform for study is the complex oxide perovskites. Complex oxides are known to exhibit a rich variety of properties such as superconductivity and ferroelectricity due to the local entanglement of the charge, spin and orbital degrees of freedom [2]. In addition, these properties have been shown to be highly tunable by strain, which is an advantage of the 2D geometry compared to bulk samples [3]. The synthesis of complex oxide nanomembranes, while highly challenging due to the 3D nature of the oxygen octahedral bonding, may offer pathways towards highly controllable flexible optical and electronic devices.

In order to take advantage of the unique properties of complex oxides, the final membrane or device must consist of high quality single-crystalline oxide materials. Recently, we have developed a new synthesis technique for crystalline complex oxide membranes and heterostructures compatible with state-of-the-art atomic-scale thin-film growth. The technique makes use of pH-neutral water to selectively etch the sacrificial layer ($Sr_3Al_2O_6$) to release the epitaxially grown thin-film from the substrate [4].

In this process, the lattice mismatch between the sacrificial layer and the thin-film plays a critical role in the growth process, membrane release, resulting nanocrystallite size, and material quality. A key question for further developing this highly promising route is to understand the scope of materials and lattice constants which can be accessed via the $Sr_3Al_2O_6$ family of materials. Here we take a representative transparent conducting oxide, La-doped $BaSnO_3$, as a model system. The large lattice mismatch of 3.9% with $Sr_3Al_2O_6$ leads to high crack density when released due to the large epitaxial strain at the sacrificial layer and thin-film interface. Employing a lattice matched sacrificial layer $(Sr,Ba)_3Al_2O_6$ (mismatch 0.4%) leads to successful fabrication of millimeter-scale large-area membranes (Fig. 1a) with crystallinity and electronic properties comparable to the epitaxial thin films (Fig. 1b), paving the way for the development of nanomembrane devices.

[1] S. Das *et al*., Annu. Rev. Mater. Res. **45**, 1 (2015).

[2] Y. Tokura and N. Nagaosa, Science **288**, 389 (2000).

[3] D. Schlom *et al*., Annu. Rev. Mater. Res. **37**, 589 (2007).

[4] D. Lu *et al.*, Nat. Mater. **15**, 1255 (2016).

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