Symposium Strain Engineering for New Functional Structures (SYSE)

jointly organized by
Section Dielectric Materials (DF),
Section Semiconductor Physics (HL),
Section Thin Films (DS), and
Section Metal and Material Physics (MM)

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Overview of Invited Talks and Sessions

(lecture room H1)

Invited Talks

SYSE 1.1	Mon	14:30–15:00	H1	**Wavy and Buckled Nanoribbons and Nanotubes: Mechanics and Applications** — •John Rogers
SYSE 2.1	Mon	16:15–16:45	H1	**Enhancing Ferroelectrics and Multiferroics using Strain** — •D.G. Schlom, M.D. Biegalski, A. Soukiassian, J.H. Haeni, J.H. Lee, R.W. Ulbricht, C.M. Brooks, Y. Jia, V. Vaithyanathan, W. Tian, X. Ke, D.A. Tenne, A.V. Rao, A. Kumar, L. Tian, A. Sharan, S. Choudhury, Y.L. Li, P. Schiffer, S. Trolier-McKinstry, X.X. Xi, V. Gopalan, L.Q. Chen, K.J. Choi, D.M. Kim, C.B. Eom, Y.B. Chen, H.P. Sun, X.Q. Pan, D.D. Fong, M.A. Zurbuchen, J.A. Eastman, P.H. Fuoss, S.K. Streiffer, P. Irvin, J. Levy, W. Chang, S.W. Kirchoefer, T. Heeg, J. Schubert, A. Bruchhausen, N.D. Lanzillotti-Kimura, A. Fainstein, R.S. Katiyar, A. Cantarero, M.E. Hawley, Q.X. Jia, C.J. Fennie, S.M. Nakhmanson, K.M. Rabe, A.K. Tagantsev, B. Velickov, R. Uecker, P. Reiche
SYSE 2.3	Mon	17:00–17:30	H1	**Patterning ferroelectric nanostructures by epitaxial strain** — •Ho Nyung Lee, Matthew Chisholm
SYSE 2.4	Mon	17:30–18:00	H1	**Curl in Photonic Crystals Induced by Drying Stresses upon Sol-Gel Infiltration** — •Vladimir Kitaev, Evangellos Vekris, Geoffrey Ozin

Sessions

SYSE 1.1–1.4	Mon	14:30–15:45	H1	**Strain engineering in semiconductors**
SYSE 2.1–2.4	Mon	16:15–18:00	H1	**Strain engineering in ferroics and photonics**

SYSE 1: Strain engineering in semiconductors

Time: Monday 14:30–15:45 Location: H1

Invited Talk SYSE 1.1 Mon 14:30 H1

Wavy and Buckled Nanoribbons and Nanotubes: Mechanics and Applications — •John Rogers — University of Illinois at Urbana/Champaign, 1304 W. Green St, Urbana, IL 61801, USA

Control over the compositions, shapes, spatial locations and/or configurations of semiconductor nanowires, nanoribbons and other nanostructures is important for nearly all applications of these materials. Although methods exist for defining some of these properties, there are relatively few approaches for controlling the two- and three-dimensional (2D and 3D) layouts of individual elements. This talk describes a mechanical strategy for creating certain classes of 3D shapes in nanoribbons that would be difficult to generate in other ways. The approach involves geometrically controlled strain coupling of these elements to elastomeric substrates. The structures that can be produced range from small amplitude, periodic one and two dimensional *wavy* geometries to periodic or aperiodic large scale buckled formations. We show that these configurations can be created in nanoribbons and nanomembranes of GaAs and Si and in individual single walled carbon nanotubes, and that these geometries can be described quantitatively with analytical and finite element models of the mechanics. As one application example, we show that certain of these structures provide a route to electronics (and optoelectronics) with extremely high levels of stretchability (up to ˜100%), compressibility (up to ˜25%) and bendability (with curvature radius down to ˜5 mm).

SYSE 1.2 Mon 15:00 H1

Wrinkled semiconductor layers: from principle to applications — •Yongfeng Mei, Dominic J. Thurmer, Francesca Cavallo, Suwit Kiravittaya, Mohamed Benyoucef, Christoph Deneke, Tim Zander, Armando Rastelli, and Oliver G. Schmidt — Max-Planck-Institut für Festkörperforschung, Heisenbergstrasse 1, D-70569 Stuttgart, Germany

The wrinkling of thin films on substrate surfaces is a well-known phenomenon. A few potential applications of wrinkles have been put forward such as force spectroscopy in cells and metrology methods [1,2]. In this talk, we present a deterministic layer wrinkling method to fabricate ordered nanochannel networks on semiconductor substrates. The method, termed "Release and bond-back of layers (REBOLA)", consists of the partial release, wrinkling and bond back of a compressively strained functional layer on a Si-on-insulator substrate surface, which seems compatible with main stream Si technology. The layer deformation after deterministic wrinkling and bond-back is reflected by the band-edge shifts of an embedded quantum well structure, which we can describe accurately by theory. To elucidate the usefulness of REBOLA, we demonstrate nanofluidic transport as well as femto-litre filling and emptying of individual wrinkles on a standard semiconductor substrate. Some interesting phenomena related to wrinkling (like self-similar folding and interference-enhanced emission) will also be addressed. Support: BMBF(03N8711). [1] A. K. Harris et al. Science 1980, 208, 177; [2] C. M. Stafford et al. Nat. Mater. 2004, 3, 545.

SYSE 1.3 Mon 15:15 H1

Stress in nanostructured semiconductors — •Silke Christiansen[1,2], Michael Becker[2], Andreas Berger[2], Cameliu Himcinschi[1], Vladimir Sivakov[1,3], Gudrun Andrae[3], Fritz Falk[3], Rajendra Singh[1], and Jens Schneider[4] — [1]Max-Planck Institute, Halle, Germany — [2]Martin Luther Universität Halle-Wittenberg, Halle, germany — [3]IPHT, Jena, Germany — [4]CSG Solar, Thalheim, Germany

Mechanical stress in semiconductor devices can either improve or degrade the device properties. Mechanical stress can be used to tailor the band structure of semiconductors. A higher mobility of charge carriers and higher device frequencies can be achieved. On the other hand, large mechanical stresses induce unwanted dislocations and dislocation motion. Mechanical stress fields can initiate crack formation that leads to breakage of whole wafers or devices. To detect the influence and the sources of mechanical stresses, the appropriate detection methods are needed. μ-Raman spectroscopy is a method that has gained recently increasing attention in solid-state physics to investigate mechanical stresses in semiconductor materials, structures and devices. In our talk we will show how Raman spectroscopy can be use to measure mechanical stress in nano-scale semiconductor layer stacks and stuctures and in polycrystalline silicon solar cell materials. μ-Raman spectroscopy is combined with real structure analysis by electron microscopy (EM) techniques such as high resolution transmission EM, analytical EM, and elecron-back scatter diffraction (EBSD) in a scanning EM.

SYSE 1.4 Mon 15:30 H1

Radial crystals and radial superlattices — •Christoph Deneke[1], Ute Zschieschang[1], Bärbel Krause[2], Neng Yun Jin-Phillipp[3], Cristian Mokuta[2], Till Metzger[2], Hagen Klauk[1], and Oliver Schmidt[1] — [1]Max-Planck-Institut für Festkörperforschung, Heisenbergstr. 1, 70569 Stuttgart — [2]ESRF, Boîte Postale 220, F-38043 Grenoble Cedex, France — [3]Max-Planck-Institut für Metallforschung, Heisenbergstr. 3, 70569 Stuttgart

Recently, a new class of radial crystals and radial superlattices has been established by the roll-up of thin solid films on a substrate surface [1-3]. We investigate these structures by X-ray diffraction and diverse transmission electron microscopy techniques. Quite generally, the superlattices comprise alternating single crystalline and non-crystalline (or poly-crystalline) layers. For example, radial superlattices out of In(Ga)As/alkanethiolate [4] or InGaAs/metal films are created. Detailed cross-sectional TEM and (S)TEM studies reveal that neighboring windings in the superlattices are closely joined together and that in some cases the interfaces show no detectable contamination. These new types of hybrid periodically modulated heterostructures might find relevance in refined optics [4] or electronics [5] applications.

[1] Ch. Deneke et al., Appl. Phys. Lett. 84, 4475 (2004); [2] B. Krause et al., Phys. Rev. Lett. 96, 165502 (2006); [3] Ch. Deneke et al., Appl. Phys. Lett. (in press) [4] R. Songmuang et al., cond-mat/0611261 [5] O. G. Schmidt et al., IEEE J. Sel. Top. Quant. Electron. 8, 1025 (2002).

SYSE 2: Strain engineering in ferroics and photonics

Time: Monday 16:15–18:00 Location: H1

Invited Talk SYSE 2.1 Mon 16:15 H1

Enhancing Ferroelectrics and Multiferroics using Strain — •D.G. Schlom[1], M.D. Biegalski[1], A. Soukiassian[1], J.H. Haeni[1], J.H. Lee[1], R.W. Ulbricht[1], C.M. Brooks[1], Y. Jia[1], V. Vaithyanathan[1], W. Tian[1], X. Ke[1], D.A. Tenne[1], A.V. Rao[1], A. Kumar[1], L. Tian[1], A. Sharan[1], S. Choudhury[1], Y.L. Li[1], P. Schiffer[1], S. Trolier-McKinstry[1], X.X. Xi[1], V. Gopalan[1], L.Q. Chen[1], K.J. Choi[2], D.M. Kim[2], C.B. Eom[2], Y.B. Chen[3], H.P. Sun[3], X.Q. Pan[3], D.D. Fong[4], M.A. Zurbuchen[4], J.A. Eastman[4], P.H. Fuoss[4], S.K. Streiffer[4], P. Irvin[5], J. Levy[5], W. Chang[6], S.W. Kirchoefer[6], T. Heeg[7], J. Schubert[7], A. Bruchhausen[8], N.D. Lanzillotti-Kimura[8], A. Fainstein[8], R.S. Katiyar[9], A. Cantarero[10], M.E. Hawley[11], Q.X. Jia[11], C.J. Fennie[12], S.M. Nakhmanson[12], K.M. Rabe[12], A.K. Tagantsev[13], B. Velickov[14], R. Uecker[14], and P. Reiche[14] — [1]Penn State U. — [2]U. Wisconsin-Madison — [3]U. Michigan — [4]Argonne — [5]U. Pittsburgh — [6]NRL — [7]FZ Jülich — [8]Centro Atómico Bariloche and Instituto Balseiro — [9]U. Puerto Rico — [10]U. Valencia — [11]Los Alamos — [12]Rutgers U. — [13]EPFL — [14]Institut für Kristallzüchtung

Aided by theoretical predictions, we have used epitaxy and the misfit strain imposed by an underlying substrate to enhance the ferroelectric properties of $SrTiO_3$, $BaTiO_3$, and $BaTiO_3/SrTiO_3$ superlattices. The enhancements include shifting the paraelectric-to-ferroelectric transition temperature by *hundreds* of degrees and maintaining ferroelectricity in $BaTiO_3$ layers as thin as one unit cell in $BaTiO_3/SrTiO_3$ superlattices. The effect of strain on $EuTiO_3$ will also be presented.

SYSE 2.2 Mon 16:45 H1

Piezoelectric strain control of thin film magnetism — •Kathrin Dörr and Christian Thiele — IFW Dresden, Postfach 270116, Dresden, Germany

Biaxial strain is a most crucial parameter influencing ferroic (ferroelectric, magnetic) properties of oxides. It is, on the other hand, not easily controlled independently of other parameters and in well-defined way. One approach for reversible biaxial strain variation in epitaxial films fitting to a pseudocubic lattice parameter of about 4.0 Angstrom is to utilize a 0.72PMN-0.28PT(001) substrate. The huge, homogeneous and nearly linear inverse piezoelectric strain of PMN-PT(001) allows one to biaxially compress as-grown films by applying electric voltage.

Ferromagnetic films of colossal magnetoresistive manganites $La_{1-x}A_xMnO_3$ (A = Sr; Ca) grown epitaxially on PMN-PT(001) have been subject to strain-dependent measurements of magnetization (M) and electrical resistance. For this family of materials, an extraordinary sensitivity towards external parameters (magnetic field, light, pressure) related to multiple phase neighbourhood is known. A pronounced shift of the Curie temperature with the strain is detected, naturally accompanied with strain dependence of M. The magnetoelectric coupling of the film-substrate system reaches a value of $\alpha = \mu_0$ dM/ dE = 6E-8 s/m (with substrate electric field E) at 300 K, revealing efficient strain-mediated coupling of the ferroic components. The observed resistive gauge factors of the films (400) further underline the strong impact of biaxial strain in manganites.

Invited Talk SYSE 2.3 Mon 17:00 H1

Patterning ferroelectric nanostructures by epitaxial strain — •Ho Nyung Lee and Matthew Chisholm — Materials Science and Technology Division, Oak Ridge National Laboratory, Oak Ridge, TN 37831, USA

Strained, single-crystalline nanoferroelectrics were produced in a method that complements recent progress towards reducing the size of ferroelectric structures by e-beam direct writing, focused ion beam etching, and self-assembly. Processes such as FIB milling or reactive ion etching suffer from the disadvantage of chemical damage induced by the nature of the processes. Chemical solution derived nanoislands produced by self-assembly are sometimes problematic due to a lack of dimensional control and the presence of poly-crystalline phases and/or defects that cause severe degradation of physical properties. In this talk, we will present a novel method to produce strained single-crystalline nanoferroelectrics. Small feature sizes (< 40 nm) of $PbZr_{0.2}Ti_{0.8}O_3$ nanostructures can be readily produced, without employing any chemical etchants or mechanical patterning. In addition, a comparison of the properties of relaxed and strained films with both highly- and weakly-polar ferroelectrics will be presented, showing that the strong sensitivity of ferroelectric polarization to epitaxial strain varies considerably for different ferroelectric perovskites.

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Invited Talk SYSE 2.4 Mon 17:30 H1

Curl in Photonic Crystals Induced by Drying Stresses upon Sol-Gel Infiltration — •Vladimir Kitaev[1], Evangellos Vekris[2], and Geoffrey Ozin[2] — [1]Wilfrid Lauirer University, Waterloo, Ontario, Canada — [2]University of Toronto, Toronto, Ontario, Canada

Colloidal photonic crystals will be introduced starting with monodisperse colloids and their self-assembly to structural control of the confinement. Recent results on curl control in inverse opal structures achieved by fine-tuning of the sol-gel infiltration process will be discussed. The driving force of structural transformations is the gradient in contraction arising from the drying stress between the sol-gel infiltrated into the porous media of the colloidal crystals and its surface overlayer. The curvature of the resulting assemblies can be consequently adjusted through the control of the overlayer thickness during the infiltration. Structural continuity (absence of cracks) is successfully achieved by optimization of the drying conditions. Optical characterization of curled photonic crystals using UV-vis microspectroscopy confirmed high structural quality of the template preserved and demonstrated that the stopband reflection of the curled colloidal photonic crystals can be described by the Bragg's law.