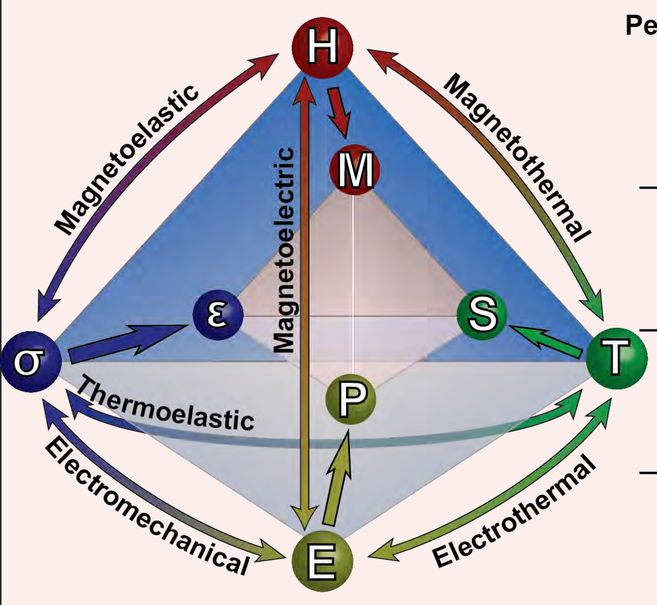
LEHIGH UNIVERSITY | Institute for Functional Materials and Devices (I-FMD)

M3 LEARNING
Multifunctional | Materials | Machine

M³-Learning: Multifunctional Materials and Machine Learning

Creating functional materials with intelligence

Multifunctional Materials

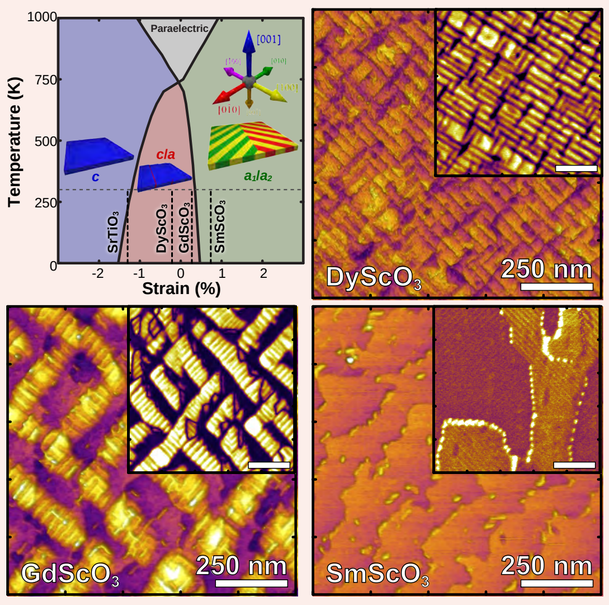


Perturbation	Response	Susceptibility
σ	ε	Elasticity
	P	Piezoelectric
	S	Piezocaloric
	M	Converse Magnetostriction
E	ε	Converse Piezoelectric
	P	Dielectric
	S	Electrocaloric
	M	Electromagnetic
T	ε	Thermoelastic
	P	Pyroelectric
	S	Heat Capacity
	M	Pyromagnetic
H	ε	Magnetostriction
	P	Magnetoelectric
	S	Magnetocaloric
	M	Magnetic

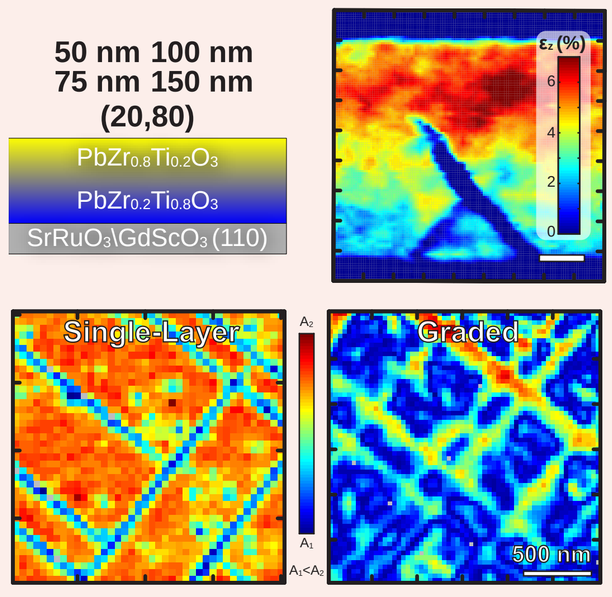
Endless possibilities: energy harvesting, sensing, memory and logic

New Modalities of Strain Engineering

Strain Engineering



Composition and Strain Gradients

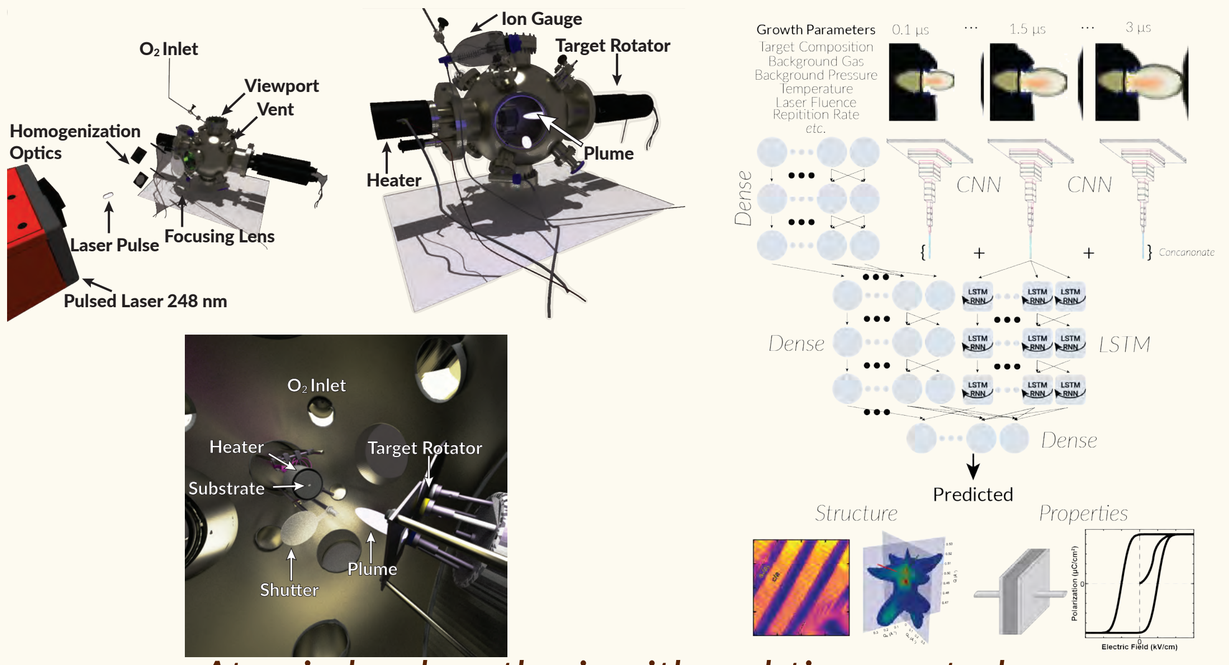


Perching ferroelectrics near structural in-stabilities → Enhanced susceptibilities

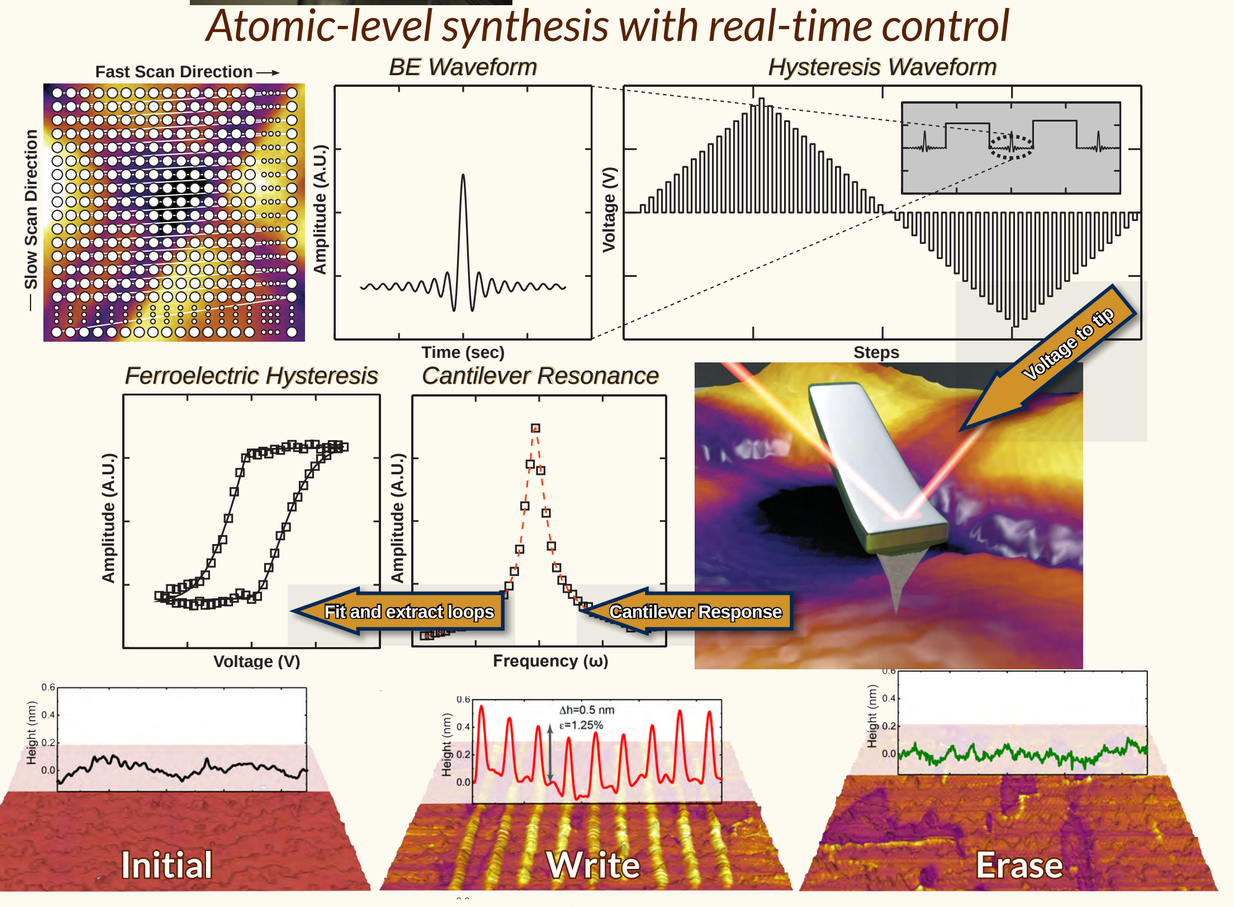
Designing novel polar topologies → Novel ferroelectric susceptibilities

Teaching an old dog new tricks

Multimodal Characterization



Atomic-level synthesis with real-time control

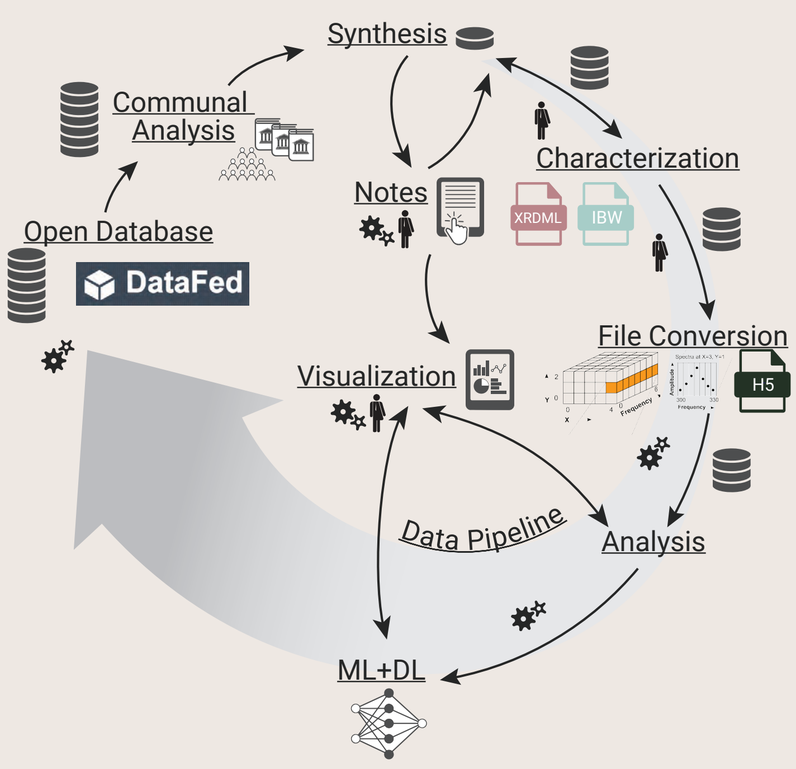


Observing the unobservable

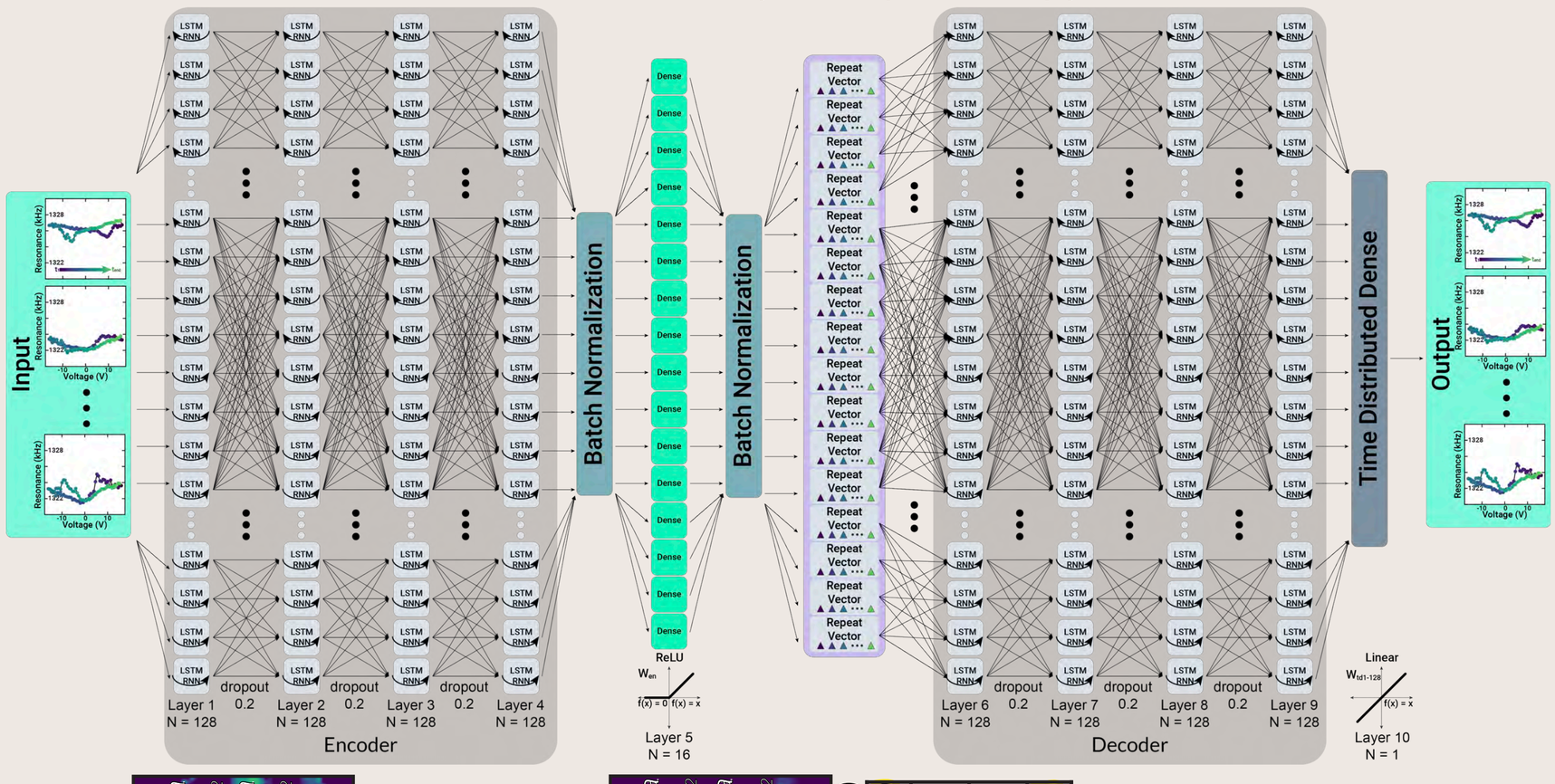
Machine Learning

Data Management

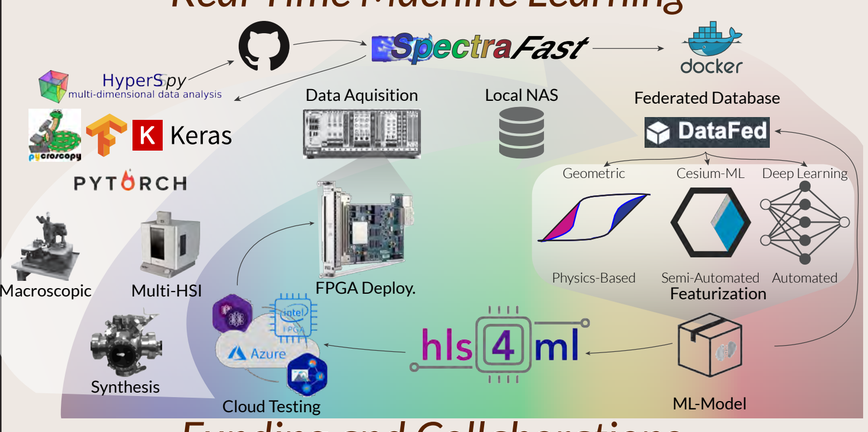
Future Workflow

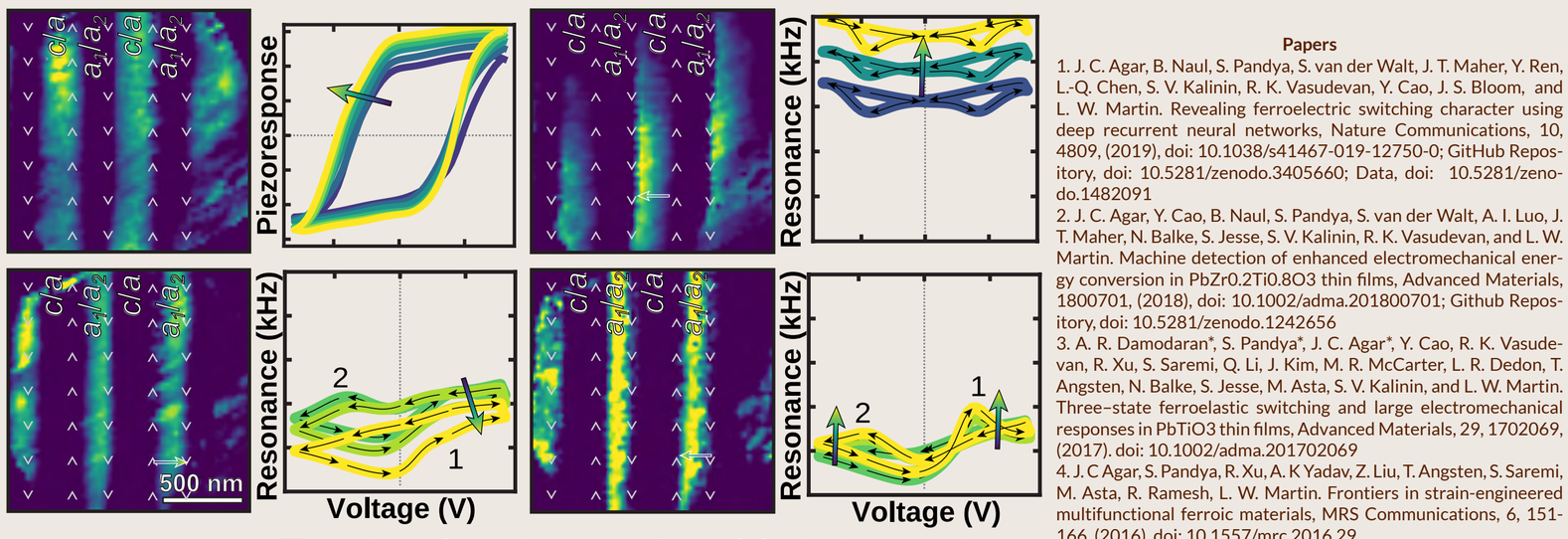


Automated Analysis of Spectroscopy



Real-Time Machine Learning





Turning data into actionable information

Funding and Collaborations

NSF · NHI · Oxford Instruments Asylum Research · Microsoft Azure · Google AI · National Instruments · Fermilab · Oak Ridge National Laboratory

Papers

1. J. C. Agar, B. Naul, S. Pandya, S. van der Walt, J. T. Maher, Y. Ren, L.-Q. Chen, S. V. Kalinin, R. K. Vasudevan, Y. Cao, J. S. Bloom, and L. W. Martin. Revealing ferroelectric switching character using deep recurrent neural networks, Nature Communications, 10, 4809, (2019), doi: 10.1038/s41467-019-12750-0; GitHub Repository, doi: 10.5281/zenodo.3405660; Data, doi: 10.5281/zenodo.1482091
2. J. C. Agar, Y. Cao, B. Naul, S. Pandya, S. van der Walt, A. I. Luo, J. T. Maher, N. Balke, S. Jesse, S. V. Kalinin, R. K. Vasudevan, and L. W. Martin. Machine detection of enhanced electromechanical energy conversion in PbZr0.2Ti0.8O3 thin films, Advanced Materials, 1800701, (2018), doi: 10.1002/adma.201800701; Github Repository, doi: 10.5281/zenodo.1242656
3. A. R. Damodaran*, S. Pandya*, J. C. Agar*, Y. Cao, R. K. Vasudevan, R. Xu, S. Saremi, Q. Li, J. Kim, M. R. McCarter, L. R. Dedon, T. Angsten, N. Balke, S. Jesse, M. Asta, S. V. Kalinin, and L. W. Martin. Three–state ferroelastic switching and large electromechanical responses in PbTiO3 thin films, Advanced Materials, 29, 1702069, (2017). doi: 10.1002/adma.201702069
4. J. C Agar, S. Pandya, R. Xu, A. K Yadav, Z. Liu, T. Angsten, S. Saremi, M. Asta, R. Ramesh, L. W. Martin. Frontiers in strain-engineered multifunctional ferroic materials, MRS Communications, 6, 151-166, (2016). doi: 10.1557/mrc.2016.29
5. J. C. Agar, A. R. Damodaran, M. B. Okatan, J. Kacher, C. Gammer, R. K. Vasudevan, S. Pandya, L. R. Dedon, R. V. K. Mangalam, G. A. Velarde, S. Jesse, N. Balke, A. M. Minor, S. V. Kalinin, and L. W. Martin. Highly mobile ferroelastic domain walls in compositionally graded ferroelectric thin films, Nature Materials, 15, 549-557, (2016). doi: 10.1038/nmat4567

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