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INTEGRATED NANOMATERIALS

Nanomaterials offer exceptional properties for photonic, electronic, magnetic, structural, mechanical, chemical, nuclear, and biological functionality. Real access to enhanced functionality remains limited, however, without connecting the nanoscale across the mesoscale to macroscale assemblies and the ability to define and control nanomaterials organization, interactions, and interfaces. Integration is essential for accessing and controlling functionality to harness nanomaterials properties while also generating new behaviors and function. Integration thus provides a route to discovering, generating, and using intrinsic and emergent nanomaterials properties, which define the two focus areas of this leadership theme.

- **Integration for strategic functionality** provides a route to access and control intrinsic nanomaterials functionality for targeted applications and program needs. This focus requires an understanding and capability for bringing ensembles of nanomaterials together in a functional form that enables control and modulation of individual and collective responses. Examples include integration of nanoscale elements into functioning electronic devices from the single element to massively-parallel scales or incorporation into matrices and interfacial materials that allow connectivity across multiple length and time scales and a range of dimensionality to address macroscale needs.

- **Integration for emergent functionality** provides a route to model, design, and generate multi-material interactions toward creation of emergent behaviors and function not present in the constituent nanomaterials. Examples include materials interactions as a route to control and modify electromagnetic energy, creation of high-strength materials via pairing of strategic thin-film compositions, thin-film integration to generate unique multiferroic responses, and multiscale integration of soft-matter building blocks to achieve desired functional responses.

Both areas of nanomaterials integration science require advancing world-class capability in four critical areas: 1) rational design, discovery, and generation and synthesis of building blocks required for function, assembly, and organization; 2) building processes for assembly and integration;

Integrated nanomaterials play a pivotal role in securing our energy future and have important applications in global security. The Laboratory's integrated nanomaterials vision has an exceptional foundation in facilities like the Center for Integrated Nanotechnologies (above), the Los Alamos Neutron Science Center, and the National High Magnetic Field Laboratory.

Materials for the Future

The Los Alamos National Laboratory Materials for the Future strategy derives from our vision to support the Laboratory's national security mission drivers.

We pursue the discovery science and engineering for advanced and new materials to intentionally control functionality and predict performance relevant to ensuring the success of the Lab's missions.

To deliver on our missions, our materials strategy builds on materials science and engineering, enabling the necessary Laboratory leadership in seven key areas:

- Complex Functional Materials
- Material Resilience in Harsh Service Conditions
- Manufacturing Science
- Actinides and Correlated Electron Materials
- Integrated Nanomaterials
- Energetic Materials
- Materials Dynamics

3) developing the science of scale-up; and 4) establishing the fundamentals of functionality via unique capabilities in characterization techniques paired with theory and modeling.

Los Alamos Leadership in Integrated Nanomaterials

Integrated Nanomaterials efforts will provide essential contributions to Los Alamos mission space including energy security, global security, and stockpile needs, as well as strategic Office of Science areas including Mastering Hierarchical Architectures, Imaging Matter across Scales, Efficient Synthesis for Tailored Properties, and Energy and Information at the Nanoscale. While there are many nanoscience-related research activities in the nation, the Laboratory's integrated nanomaterials vision has an exceptional foundation in facilities like the Center for Integrated Nanotechnologies (CINT), the Los Alamos Neutron Science Center, and the National High Magnetic Field Laboratory. In particular, CINT, as the only Nanoscience Research Center embedded in two National Nuclear Security Administration national laboratories (Los Alamos National Laboratory and Sandia National Laboratories), was *designed* to apply nanomaterials solutions to national security problems. An example of such a challenge is advanced communications based on single-photon emitters and metasurfaces and in tracking, tagging, locating. Among the five Nanoscience Research Centers, CINT has a distinguishing strength in nanomechanics. As a joint Los Alamos and Sandia organization, CINT plays an important and increasing role in quantum information science with applications to next-generation computing and cryptography.

Key Science Questions

- How do we probe complex, multi-scale interactions, dimensionality, interfaces, and surface at the variety of spatial and temporal scales of relevance?
- Can we predict, design, and control defects, nanostructures, and interfaces to yield emergent functionality and targeted behaviors from materials interactions?
- How do we control charge, energy, and material transport and transformation of energy and excitations?
- How do we combine theory and experiment to achieve functionality by design and control interactions for optimization and emergence of desired response?
- How can we attain low-cost efficient upscaling of nanostructures to generate arbitrary two-dimensional and three-dimensional hierarchical assemblies while capturing properties in bulk?

10-year End State

Discoveries and predictive understanding of nanoscale phenomena provide the foundation for integrating nanomaterials into hybrid materials and device architectures with relevance to the mission needs at Los Alamos. To catalyze this transition, we envision a Laboratory center of excellence in integrated nanomaterials that serves as a translational portal. The composition of this portal in terms of facilities, capabilities, and staffing will be fluid and may be across multiple line organizations. It will house key personnel as a single point of contact to connect open, peer-reviewed science and technology with the specific mission needs of the Laboratory. Toward programmatic support of this goal, an effective strategy and capability for advancing technology readiness level (TRL) 2-3 research to higher levels can link fundamental efforts and mission needs. Nano-capable integrated facilities for radiological and surrogate materials, including secure limited-access facilities, would provide important enablers for MaRIE, the Laboratory's proposed experimental facility concept for investigating matter-radiation interactions in extremes. The portal must have strong connections to all program offices and must be recognized across the Laboratory as the single coordinating entity to translate discovery nanoscience to mission needs. Achievement on this goal will be realized when key contributions from this center are an integral aspect of higher level milestones for research and development supporting national security programs through hydrodynamic testing, science-delivered alternatives for life extension programs, and applied technologies for global security.

For more information, please see materials.lanl.gov or send email to materials@lanl.gov.

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