# Microelectronics:

- role that basic science is playing & could play
- work going on at Argonne

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## Trajectory for future microelectronics

1. Energy efficiency is the looming challenge: peta-scale to zeta-scale HPC needs >100X improvement in power efficiency. This is but one example.
2. Memory has lagged logic development leading to the "memory bottleneck": increase connectivity
3. We will see the fragmentation of systems into chiplets and their assembly on a common substrate or package (Heterogeneous Integration).
   - What is today on a rack or large printed-circuit-board (PCB), will be miniaturized onto a panel substrate.
   - Volumetric integration density of components will superscale; the z direction will emerge in importance.
   - Ultimately, such heterogeneous integration (HI) will minimize the distinction between inter-chiplet and intra-chiplet access latency

## Climate

- Community aware of relevant problems for microelectronics are often not the community with skills to solve them
- We need new knowledge in the physics & chemistry of materials—what we know is not enough for what we need to build.

# Materials research imperatives for microelectronics

1. **Physics, chemistry, & computational science of microelectronic materials** for fast, accurate predictability
   - modeling non-equilibrium configurations & defective materials
   - modeling of complex processes across scales
   - AI guided materials discovery: this will not happen without large, open databases for training
2. **Atom-scale, deterministic nanofabrication in three dimensions**
   - Direct-write alternates to lithography that enable more facile 3D fabrication, and less material waste
   - Atomic scale deposition and etching of conformal surfaces; control over selective deposition processes

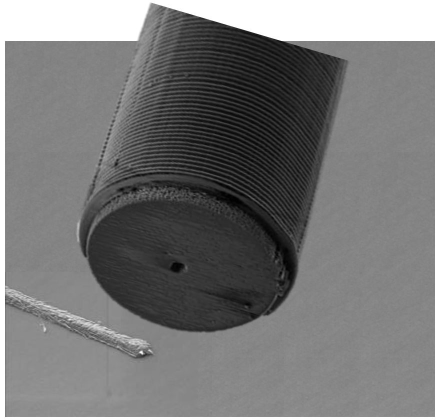
# Materials research imperatives for microelectronics

3. **Carrier and thermal transport physics and materials for three-dimensional, multi-scale and imperfect heterogeneous environments**
    - thermal physics models and new thermal materials & strategies for heat removal
    - the physics of transport in small interconnects, polycrystalline electronics
    - organic substrates with mechanical and thermal properties approaching inorganic materials
    - exploiting new state variables for logic & memory (e.g. photons, protected states, etc.)
4. **New physics based computational models & architectures**
    - leverage noise, “work” the analog-to-digital interface
    - new thinking in the way we move power, heat, and information
5. **Characterization of three-dimensional structures**
    - atomic scale chemical and physical resolution in X-Y-Z ; non-destructive methods for high throughput
    - in-operando studies for dynamically driven processes in response to stimuli (e.g. voltage in a device)

# Microelectronics related research@Argonne

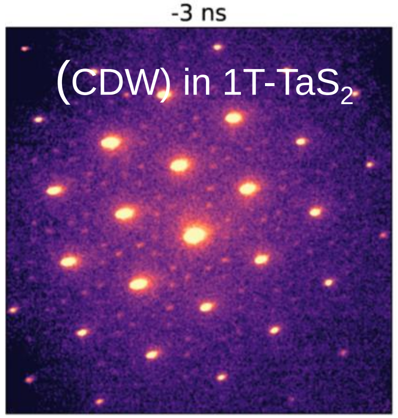
- **Ultra-Dense, Near-Perfect, Atomic and Synaptic Memory**: co-design tools & materials for cross-bar memories, strategies for very dense optical memory at defect/dopant sites.
- **Threadworks: AI approaches to extracting/processing data from high data rate** (100s of TB/s) detectors for HEP and NP.
- **Advanced characterization**:
  - Non-destructive X-ray imaging in 3D (APS-U will provide >100X beam coherence, permit field of view to mm-scale at ~10nm voxel resolution / currently ~100um FOV at ~30nm resolution))
  - Ultrafast, voltage triggered electron microscopy
- **New synthesis approaches**:
  - direct-write additive fabrication
  - atomic layer deposition

micro-evaporator on a chip for direct-write



Doi, Guha

ultrafast voltage triggered EM

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