Quantum Simulation for Materials Discovery
Preparing Large Arbitrary Configurations of Atoms

HUCK KIM, SHAHEER RANA, ANDREW WATFORD, ZHIQIAN DING, ARTEM ZHUTOV, KENT UENO, PARTH PADIA, ANASTASIIA MASHKO, ALEXANDRE COOPER-ROY

Programmable quantum many-body systems

Preparing large arbitrary atom configurations for synthetic materials

Engineering synthetic quantum materials requires programmability so that different properties can be simulated. These properties can be simulated using quantum many-body systems which require atoms arranged in specific geometries to form a large number of atom configurations so that exotic quantum phenomena can be engineered and observed.

Programming atom interactions

By preparing large configurations of atoms that can model arbitrary geometries, reliable and accurate quantum many-body systems could be made. Using this, researchers could:

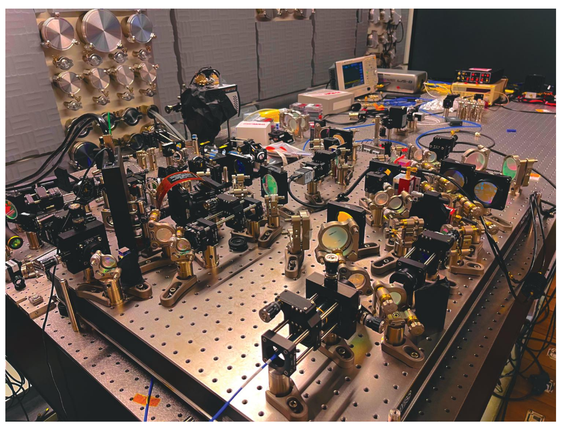
- Assemble large synthetic quantum materials expected to exhibit interesting physical phenomena with programmable geometry
- Use the configuration in many-body simulator to model interactions and behaviors for real life applications
- Replace missing or lost atoms at a specific location, as well as displace atoms to engineer **any desired interaction** between any two atoms.

Creating large, homogenous arrays of static and dynamic optical traps

A laser beam passing through a diffractive optical element can be multiplexed into an array of beams, each of which can trap an individual atom.

The optical element can be updated in real-time using a feedback control system to enable programmable arrays of optical traps to deterministically assemble arbitrary configuration of individual neutral atoms.

Integrated atom trap reconfiguration system

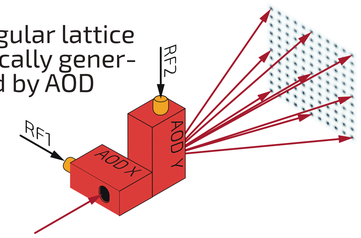


Controlling and reconfiguring dynamic optical traps in real-time

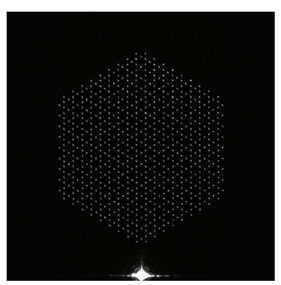
A Spatial Light Modulator (SLM) and Acousto-Optical Deflector (AOD) are used to create **static** and **dynamic** optical traps needed for quantum many-body simulation.

An EMCCD camera captures the optical trap grid to produce a greyscale intensity profile. This is convolved with a point spread function and using a modified weighted Gerchberg-Saxton algorithm, instructs the SLM or AOD for reconfiguration.

Rectangular lattice dynamically generated by AOD



Graphene generated with 756 traps by SLM (pictured by EMCCD)



Benchmarking

Acheiving state-of-the-art performance requires:

- Large arrays using **high-power**, low-noise lasers and optical elements with a high-diffraction efficiency.
- **High-resolution** imaging system with large field of view and **low aberrations**.
- Closed-loop optimization system to maximize diffraction **efficiency** and guarantee homogeneity of **intensity**.

Demonstrating dynamic traps

This poster is accompanied by a demonstration of a fully functional and interactive system that can model user-specified arbitrary geometries in a 101x101 optical trap grid.

Furthering performance:

Additional opportunities include:

- Increasing the grid size to **1000x1000** traps
- Inducing **specific interactions** between atom configurations to observe quantum phenomena