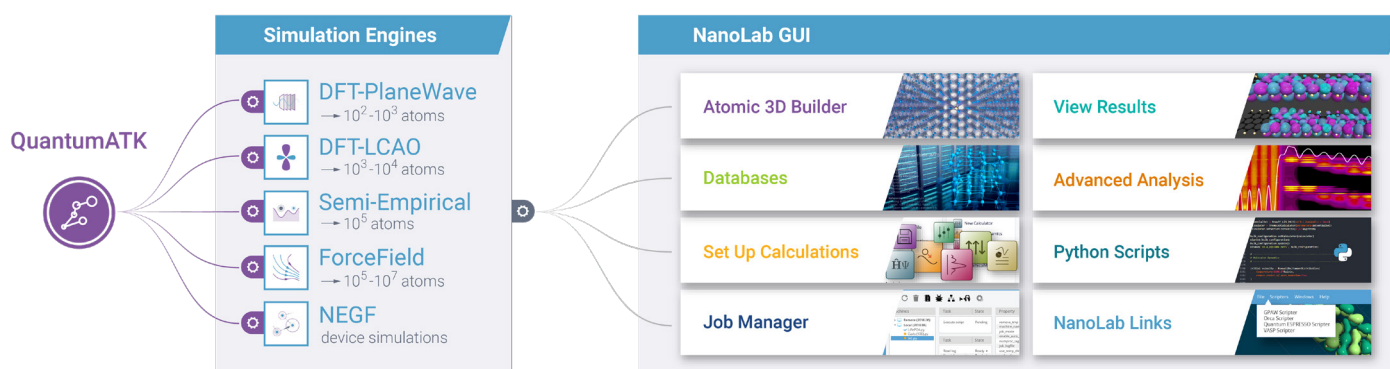


QuantumATK Platform for Universities & Government Labs

QuantumATK is a complete and fully integrated software suite for atomic-scale modeling for academic research, professionally engineered using state-of-the-art scientific and software-engineering methods. It combines the power of a Python scripting engine with the ease-of-use provided by an intuitive NanoLab graphical user interface (GUI). All simulation engines share a common infrastructure for analysis, ion dynamics, and parallel performance techniques.



Core Features of QuantumATK

NEGF Method of Nanoscale Device and Transport Simulations

Non-Equilibrium Green's function (NEGF) module works with DFT-LCAO, Semiempirical and ForceField Modules (see next page)

- ▶ **Types of Systems:** Nanoelectronic Devices & Interfaces (2-Probe), Surfaces (1-Probe, beyond slab approximation)
- ▶ **Include:**
 - An effective doping scheme to simulate doped semiconductors
 - Metallic gate electrodes, dielectric screening regions and implicit solvent models
 - Surface, defect, interface, and grain boundary scattering effects
 - Electron-phonon coupling (EPC) effects (with MD-Landauer, STD-Landauer, and inelastic transmission methods)
 - External electric fields
 - Relaxation of device geometries
 - Multilevel parallelism up to 1000s of cores
 - Options to balance performance vs. memory usage
- ▶ **Calculate:**
 - Electrical characteristics, such as I-V curves, on/off ratio, subthreshold slope, drain-source saturation voltage, drain-induced barrier lowering, transconductance
 - Transmission spectrum, eigenvalues, eigenchannels, device density of states (DOS), etc.
 - Schottky barriers and interface resistance (e.g. for metal-semiconductor contacts)
 - Thermal conductance/conductivity of materials, nanostructures, interfaces, etc.
 - Phonon-limited mobility and resistivity of materials
 - Tunnel magnetoresistance ratio, spin-polarized tunneling current, and bias-dependent spin-transfer torque for material stacks that comprise the magnetic tunnel junctions
 - Photocurrent and open circuit voltage for solar-cell devices and LEDs
 - Band-alignment, Schottky barriers, and work functions for thin film/surface heterostructures
 - Electronic surface states in external electric fields
 - Insight into catalytic activity of transition metal and transition metal oxide surfaces

Core Features of QuantumATK

- **DFT-LCAO:** Simulation engine for density functional theory (DFT) using pseudo-potentials and linear combinations of atomic orbitals (LCAO) basis sets.
- **DFT-PlaneWave:** Simulation engine for DFT using pseudo-potentials and plane-wave basis sets.
- **SemiEmpirical:** Semi-empirical simulation engine for using DFTB, extended Hückel, Slater-Koster, and other tight-binding models.
- **ForceField:** Simulation engine for atomic-scale simulations (e.g. molecular dynamics (MD)) using classical potentials.

DFT-PlaneWave

↑ 10^2 - 10^3 Atoms

DFT-LCAO

↑ 10^3 - 10^4 Atoms

SemiEmpirical

↑ 10^5 Atoms

ForceField

↑ 10^5 - 10^7 Atoms

► **Types of Systems:** Molecules, crystals, polycrystals, nanostructures, nanoparticles, alloys

► Works with NEGF method for simulations of nanoelectronic devices, interfaces, surfaces, solar-cells

► **Use:** More than 300 LDA/GGA/MetaGGA (e.g. SCAN) DFT functionals

► Hybrid functionals using the ACE approximation

► Van der Waals models: DFT-D2 and DFT-D3

► Hubbard U term for LDA and GGA

► Methods for accurate band gap calculations of semiconductors and insulators

► Norm-conserving Troullier-Martins PPs (FHI, SG15/PseudoDojo)

► Projector-augmented wave (PAW) PP method (beta)

► Predefined numerical atomic orbital basis sets for different accuracy levels

► Plane wave basis sets with automatic default cut-offs

► Spin settings: unpolarized, polarized, noncolinear, noncollinear spin-orbit

► Built-in Slater-Koster models for group IV and III-V semiconductors, extended Hückel model with over 300 basis sets and Tight-Binding models for strained systems

► More than 300 empirical classical potentials included, Python interface for adding your own or literature potential, support for custom combination of potentials

► Gates, dielectric regions or implicit solvent models in devices or periodic structures

► **Perform:** Calculations of band structure, fat band structure, (P)DOS, Fermi surface, and many more

► Boltzmann transport calculations of conductivity/mobility tensor, Hall coefficient and Hall conductivity tensor, Seebeck coefficient and ZT including electron-phonon coupling (EPC)

► Geometry and unit cell optimization using LBFGS and FIRE methods

► Molecular dynamics (MD) (NPT, NVT, NVE, ...) simulations for studying mechanical (e.g. creep simulation), thermal properties, and physical processes (e.g. thin film growth); part of the MD-Landauer simulations to include electron-phonon coupling (EPC) effects

► Time-stamped force-bias Monte Carlo simulations as an alternative to MD for long time-scale equilibration, deposition, amorphization, diffusion, sampling of rare events

► Nudged elastic band (NEB) for reaction path optimization (e.g. to get insight into catalytic activity of transition metal and transition metal oxide surfaces)

► Adaptive kinetic Monte Carlo (AKMC) for long timescale kinetics (e.g. diffusion kinetics)

► Phonon modes (part of the STD-Landauer method to include EPC effects), phonon bandstructure, DOS, and thermal transport simulations

► **Benefit from:** Multilevel parallelism (threading + MPI) up to 1000s of cores. Parallelize over k-points/basis functions/NEB images/AKMC searches/bias points, etc.



Core Features of NanoLab GUI

NanoLab: Graphical User Interface (GUI) for all QuantumATK simulation engines: LCAO, PlaneWave, SemiEmpirical, ForceField and NEGF (transport).

Atomic 3D Builder

- ▶ Build your own molecules, crystals, nanostructures, etc. using advanced selection and move tools.
- ▶ Use 1st party plugins for setting up interfaces, nanowires, nanoparticles, polycrystals, alloys, cleave surfaces.
- ▶ Use Device tools for setting up device structures, including adding gate electrodes, dielectric screening regions, doping semiconductors.
- ▶ Set up and pre-optimize nudged elastic bands (NEB) reaction paths.
- ▶ Import ready-to-use structures from the internal NanoLab database and online databases such as Crystallography Online Database and Materials Project.
- ▶ Create your own internal databases using e.g. MongoDB or MySQL.
- ▶ Use Python console for having programmatic access to interact with the configurations in the Builder. Create pre-defined scripts to automate repeated tasks.

Visual Tool for Setting Up Calculations and Workflows

- ▶ Set up DFT-LCAO, DFT-PlaneWave, SemiEmpirical, ForceField, and NEGF for device and transport simulations.
- ▶ Compute the electronic, optical, thermal, magnetic, mechanical, electron-phonon coupling, piezoelectric, thermoelectric, and other material properties of nanostructures, bulk materials, and surfaces.
- ▶ Use specialized interface to set up interdependent tasks for obtaining I-V characteristics, magnetic anisotropy energy, defect formation energies and transition levels.
- ▶ Set up molecular dynamics simulations using models such as NVT, NVE, NVT/NPT, etc.
- ▶ Optimize geometry (use the specialized interface for relaxation of devices and interfaces).
- ▶ Edit input files (python scripts) using the NanoLab editor.
- ▶ Save your calculator settings and workflows as templates and reuse them in future calculations.

Job Manager

- ▶ Submit and run jobs from the GUI in serial, using threading and in parallel using MPI, or OPENMPI and MPI together.
- ▶ Submit jobs from the GUI to local or remote machines (Torque/PBS, LSF, SGE, SLURM).

3D Data Viewer/Movie Tool

- ▶ View optimized geometry, calculated Bloch states, fermi surface, electron (difference) density and other properties.
- ▶ Use interactive 3D measurement tool for distances and angles and use plugins to compare two configurations.
- ▶ Edit graphical properties, such as atom colour, background, light properties, etc.
- ▶ Visualize very large data sets (1M+ atoms and bonds).
- ▶ Export images and movies to most common graphical formats.
- ▶ Visualize the dynamics of MD trajectories, phonon vibrations, NEB paths, etc.

2D Plotting

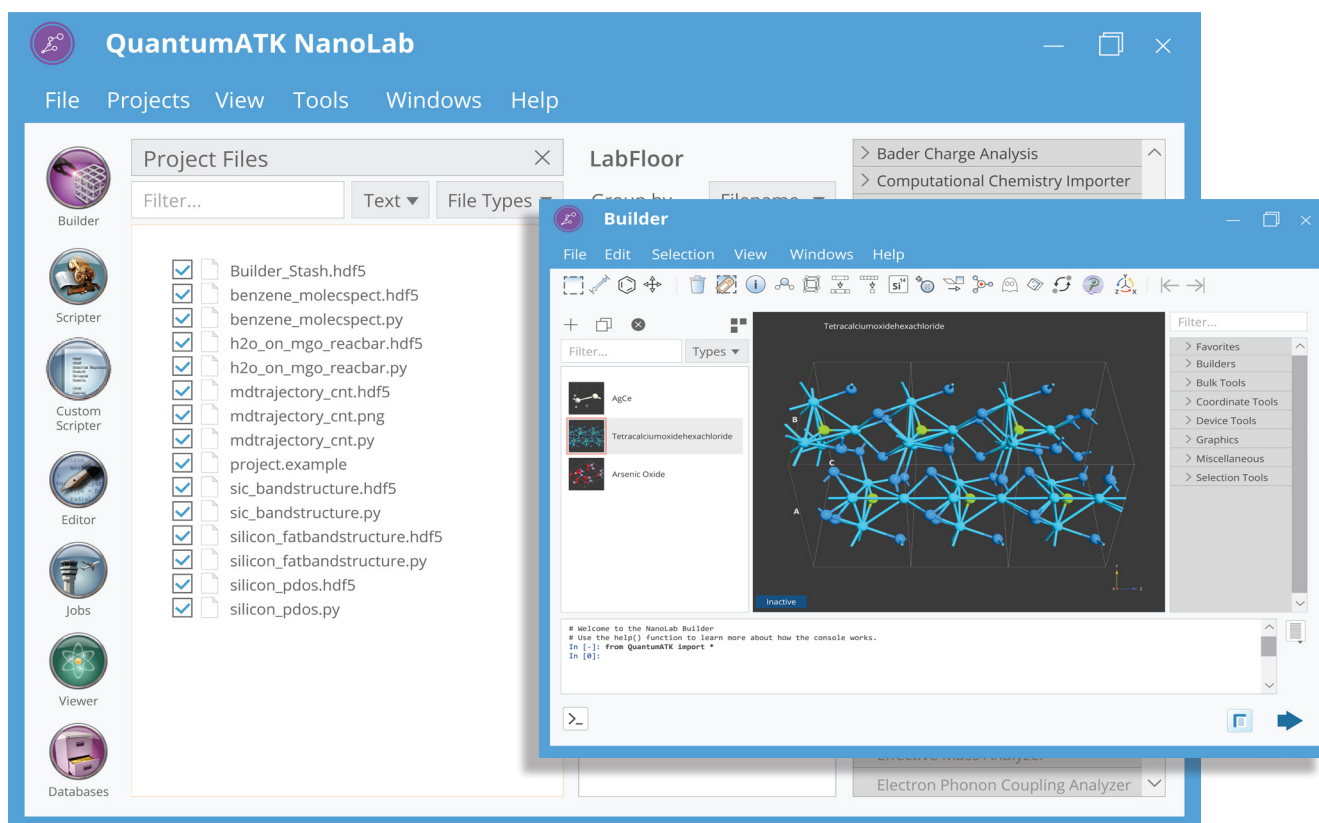
- ▶ Plot bandstructures, density of states (DOS), I-V curves, defect formation energies, optical spectrum, etc.
- ▶ Perform advanced editing of plots, such as changing color, line, width, etc. of multiple items (several bands for instance) at once, changing title axes, legend, etc., editing grid layout, and adding annotations like arrows and labels.
- ▶ Save customized plots for further analysis and reuse plot setups with new data.
- ▶ Link and combine plots, e.g. band structure and DOS, for more insightful analysis.
- ▶ Fit data to linear and other models and measure directly in graphs.

Project Management

- ▶ Organize data files into projects.
- ▶ Easily transfer projects between computers, or share with other users.
- ▶ Overview all data in a project, or focus on particular subsets, then combine data sets from different files for advanced analysis.

Plugin API

- ▶ Write addons and plugins in Python, using a simple API to add new functionality to NanoLab.
- ▶ Add support for additional external codes.
- ▶ Add new features to the NanoLab Builder (anything from simple operations to fully interactive widgets).
- ▶ Import/export of structures in external file formats.
- ▶ Add new data analysis capabilities and plot types.
- ▶ Use Add-on manager for installing plugins written by Synopsys QuantumATK team or users.
- ▶ Most functionality in NanoLab is plugin (addon) based.



Core Features of NanoLab Links

NanoLab Links: Module enabling NanoLab to interface other codes.

Interface to VASP

- ▶ Generate input files using interactive scripiter, supporting most VASP functionality.
- ▶ Add custom lines to and preview the INCAR file.
- ▶ Read data files for plotting and data analysis (OUTCAR, CONTCAR, CHGCAR, DOSCAR, EIGENVAL, CHG, PARCHG, ELFCAR, XDATCAR).
- ▶ Plot band structures, FatBandstructure (for analysis of the spd- and site projected character of the bandstructure), DOS, etc.
- ▶ Generate initial NEB paths using the IDPP method.
- ▶ Set up constraints.
- ▶ Visualize NEB paths and barriers.

Interface to QuantumESPRESSO

- ▶ Generate input files using interactive scripiter.
- ▶ Read and plot charge densities, DOS, band structures.
- ▶ Import trajectories generated by QuantumEspresso.

Interface to GPAW

- ▶ Generate input files using interactive scripiter.
- ▶ Read and plot charge densities.

Interface to Orca

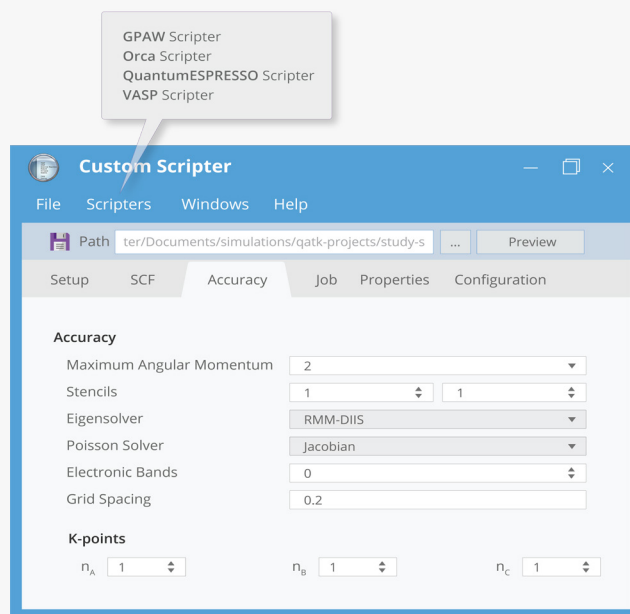
- ▶ Generate input files using interactive scripiter.
- ▶ Read and plot charge densities.

Interface to LAMMPS

- ▶ Create and export advanced structures.
- ▶ Import trajectories to make movies, calculate local structure, plot RDF, etc.

CCLib

- ▶ Import files from various quantum chemistry codes.



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