16. DESIGNING NANOSTRUCTURES FOR NEW FUNCTIONAL MATERIALS

B.B. Rath
Naval Research Laboratory
Washington, DC 20375-5341, USA

Abstract

High demands on materials performance, particularly for functional applications in miniaturized systems, have brought revolutionary changes in materials synthesis, processing, and fabrication concepts. Recent advances have demonstrated that materials with nanometer scale structures can be successfully designed at the atomic and molecular levels to exhibit unique properties by using many methods. Improved and unexpected properties of these materials have an impact on a wide spectrum of phenomena including superconduction, magnetism, quantum electronics, non-linear optics, cluster stability, and nucleation and growth. Concurrent with innovative processing and fabrication, new characterization tools such as scanning tunneling microscopy, atomic force microscopy, and magnetic force microscopy have revolutionized our understanding of interatomic interactions and structures of atomic and molecular self-organization. Selected observations of recent studies in this emerging field will be presented with recommendations for future research.

Editor's note: The following materials have been reproduced from the viewgraphs used by B.B. Rath in his presentation.

Materials Research In A New Era

"I am inspired by the biological phenomena in which chemical forces are used in repetitious fashion to produce all kinds of weird effects (one of which is the author)."

— Richard Feynman
Eng. and Sci. Mag.
Cal. Tech. Feb. 1960

Materials: Unprecedented Technological Advances

Superconductivity	Magnetism
Electronics & sensors	Optics and optoelectronics
Ceramics	Composites (smart materials)
Biomaterials	Intermetallics
Carbons	Under-dense materials
Polymers	Ferrous alloys
Materials for the environment	

Characterization tools --------------------------------------STM/AFM, atom-resolved TEM, angle-resolved Auger synchrotron radiation
Synthesis/processing --- MBE, MOCVD, PLD, spin casting, spray pyrolysis, E-beam/X-ray, UV lithography
High performance computing ------------------------------- density functional approach, Car-Parrinello, molecular dynamics, Monte Carlo (see Fig. 16.1)
Industrial pull -- improved system performance, economic competitiveness

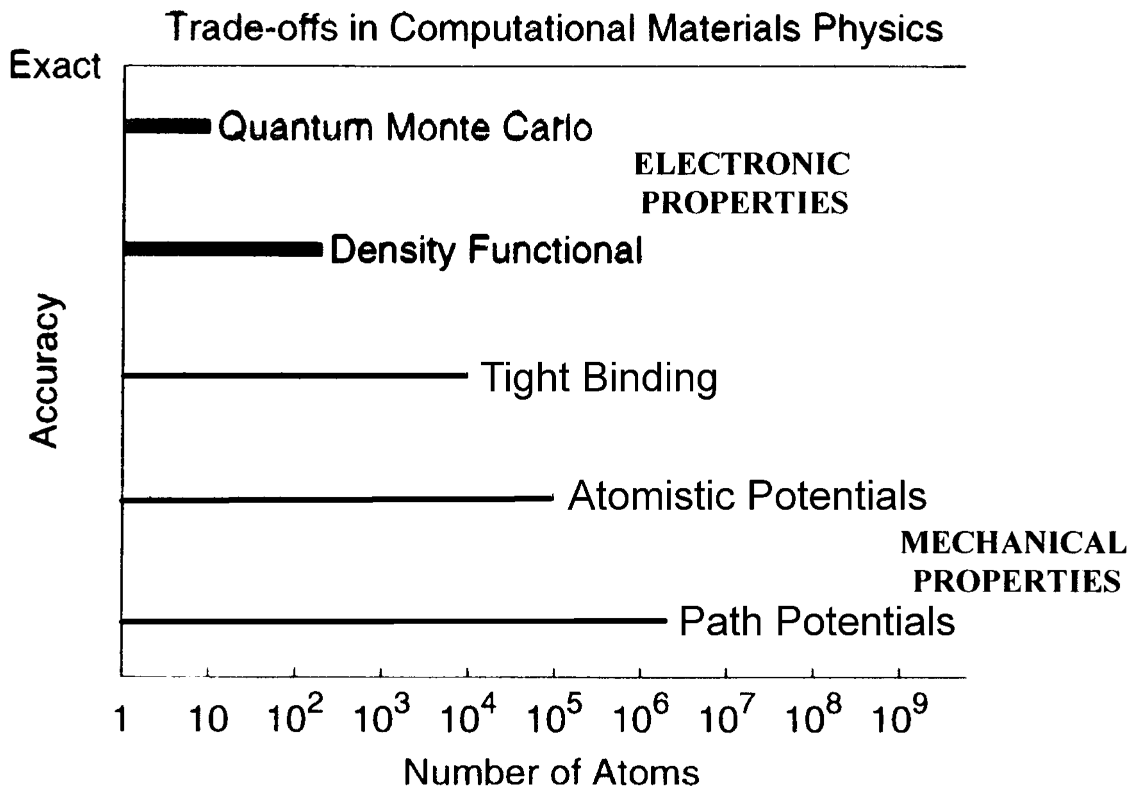

Fig. 16.1. Trade-offs in computational materials physics.

Economic Drivers

- INFORMATION PROCESSING (SENSORS – COMPUTER DEVICES – ACTUATORS)
  (terabit memory density, speed, flat panel display, microfabricated sensor/ actuator)
- TELECOMMUNICATIONS
  (faster optoelectronic devices, dimensional tolerances)
- BIOTECHNOLOGY/ MEDICINE
  (single molecule detection/identification, in-vivo diagnose/ dispense, prosthesis)
- PRECISION ENGINEERING
  (metrology, semiconductor fab, micro-instrumentation, pointing/tracking, high energy laser, X-ray optics)
- MAINTAINABILITY/RELIABILITY
  (friction, wear, adhesion, fracture, corrosion)

Proximal Probe

Operating classes with order of magnitude lateral resolution

I.	**Electron Tunneling**	
	Scanning Tunneling Microscopy	0.1 nm
	Scanning Tunneling Spectroscopy—electronic, EPR	0.1 nm
	Laser Assisted Tunneling Spectroscopy—electronic, vibrational ?	0.1 nm
	Spin Polarized Tunneling—magnetic	0.1 nm
	Ballistic Elec Emission Micro-/Spectroscopy—buried interface	1 nm
II.	**Proximally Focused Field Emission**	
	Scanning Electron Microscopy	1 nm
	Microfabricated Field Emission Sources	1 nm
	Electron Excited AES, PES, Fluorescence, Luminescence	10 nm
III.	**Force (10^{-7} To 10^{-14} Newtons)**	
	"Atomic Force" Microscopy—repulsive, nanomechanics (incl. tribology)	1 nm
	Surface Force—Van der Wall, patch, electrostatic, ...	0.1 – 10 nm
	Magnetic Force Microscopy—magnetism	10 nm
	Surface Potential—single electron	10 nm
	Capacitance—dielectric	10 nm
IV.	**Near Field**	
	Optical—evanescent wave tunneling, nanoaperature, fluorescence	10 nm
	Chemical Potential—thermocouple junction	1 nm
	Acoustic—elastic	10 nm
	Conductance—membrane transport	10 nm
	Electrochemical—surface reactivity	10 nm