IOCN 2025 Conference

The 5th International Online Conference on Nanomaterials

22–24 September 2025 | Online

MDPI

Modeling and Analysis of Mechanical Behavior in Nanowires, Nanotubes, and Nanopillars

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INTRODUCTION & AIM

Nanowires (NWs)
- Size-dependent mechanical behavior: Smaller nanowires exhibit higher strength than bulk materials.
- Elasticity, plasticity, and anelasticity vary significantly with diameter and length.
- Presence of planar defects and grain boundaries strongly influences deformation and fracture behavior.

Nanotubes (NTs)
- Exhibit ultra-high Young's modulus and tensile strength, especially carbon nanotubes (CNTs).
- Smaller diameters often result in higher stiffness and strength.

Nanopillars
- Mechanical response is comparable to NWs and NTs, showing size-dependent strength.
- Typically studied under uniaxial compression to investigate yield strength and failure mechanisms.
- Useful in micromechanical testing to simulate stress behavior at nano and microscale.

METHOD

◦Testing and Characterization Techniques

◦ In Situ Testing

◦• Real-time mechanical testing within SEM or TEM environments..

◦Atomic Force Microscopy (AFM)

◦• Measures Young's modulus, hardness, and yield strength through nano-indentation or nano-bending.

◦• Allows precision manipulation of individual nanostructures.

◦Molecular Dynamics (MD) Simulations

◦• Atomistic-level modeling under various load conditions.

◦• Explores the influence of surface defects, grain boundaries, and geometric factors on mechanical performance.

◦Factors Influencing Mechanical Behavior

◦ Size and Geometry

◦• Smaller dimensions often lead to increased strength and stiffness.

◦• Mechanical response is strongly dependent on cross-section, aspect ratio, and curvature.

RESULTS & DISCUSSION

Young's Modulus
- Nanowires (NWs): ~76 GPa (e.g., ZnO nanowires)
- Nanotubes (NTs): Exceeds 1 TPa (especially for single-walled carbon nanotubes)
- Nanopillars: High modulus expected; depends on material composition

Fracture Strain
- NWs: ~8% (ZnO nanowires)
- NTs: Extremely high tensile strength (~200 GPa)
- Nanopillars: High fracture strain; influenced by both material and nanoscale geometry

Size Effects
- NWs: Show "smaller is stronger" behavior; strong size-dependent mechanical enhancement
- NTs: Prominent surface-to-volume ratio effects impact elasticity and deformation
- Nanopillars: Exhibit similar trends; mechanical response varies with size and aspect ratio

Primary Applications
- NWs: Used in sensors, actuators, and nanoelectromechanical systems (NEMS)
- NTs: Common in reinforced composites and NEMS
- Nanopillars: Applied in energy devices, sensors, and mechanical testing platforms

CONCLUSION

Nanostructures exhibit exceptional mechanical properties due to their size-dependent behavior and high surface-to-volume ratios.

Nanowires show moderate Young's modulus and fracture strain, making them suitable for sensing and actuation applications.

Nanotubes, particularly carbon nanotubes, demonstrate ultra-high stiffness and strength, ideal for use in advanced composites and NEMS.

Nanopillars, though less extensively studied, exhibit promising mechanical characteristics for energy and microscale device applications.

Size effects play a critical role across all nanostructures, with "smaller is stronger" being a consistent observation.

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