Quantum Limits to the Force Sensitivity of a Micromechanical Resonator Observed by an Optical Interferometer and Implications for the Large-Scale Simulation of Quantum Systems

Dr. Lee E. Harrell
Department of Physics
United States Military Academy
West Point, New York

Sponsor: Dr. John A. Sidles
Professor
Department of Orthopædics and Sports Medicine
University of Washington, Seattle, WA

ABSTRACT:

Optical interferometers are commonly used to observe the oscillations of nanomechanical force sensors with great precision. Picometer-scale oscillations—a factor of 10^6 smaller than the wavelength of the light—are readily observable with fiber optic interferometers constructed from off-the-shelf components, and thermally driven Brownian motion is observable in well-isolated micromechanical oscillators at millikelvin temperatures. While state-of-the-art force measurements are limited by thermal fluctuations of the oscillator, the drive towards observation of single protons via the magnetic dipole-gradient force raises the question of the ultimate limits of interferometer sensitivity. In these experiments, both the interferometer light and the mechanical oscillator have the potential to exhibit quantum behavior, and a microscopic model of their interaction will be necessary for a full analysis. We present a microscopic model of this interaction based on entanglement of interferometer photons with the mechanical oscillator and discuss the limitations of force sensitivity of the oscillator imposed by photon back action on the oscillator.

This measurement/control formalism is a central element of a broader research program whose strategic objective is the efficient simulation of large-scale quantum systems. Examples of such systems include biological molecules and spintronic devices. These systems are typically coupled to both to readout devices (e.g., nanoscale cantilevers and field-effect transistors) and to ambient thermal fluctuations. At present, the best-known algorithms for simulating such systems require exponentially large computing resources as the number of degrees of freedom is increased. We discuss a new class of simulation algorithms for which the required resources scale only polynomially with the number of spins. These new algorithms, if they fulfill their early promise, will allow the engineering design of radically new large-scale quantum technologies to proceed with confidence that "if we build it, it will work".

KEYWORDS: Magnetic Resonance Imaging, Interferometer, Quantum Measurement and Noise

CONTACT: Dr. John A. Sidles, Professor, Department of Orthopædics and Sports Medicine, University of Washington, Seattle WA, Tel: (206) 543-1720, Email: sidles@u.washington.edu