A micro-fabricated surface ion trap on a high reflectivity optical mirror

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Introduction

Motivation:
- Multi-qubit operations in a large scale ion trap quantum computer must involve interconnected trapped ions at several designated sites, without cross-talk to other ions. One suitable disconnection method maps quantum states of ions to photons, using strong atom-light interactions. This can be accomplished by coupling ions to high-finesse optical cavities.

Challenges:
- (i) the trapping potential can be perturbed in the presence of dielectric mirrors, which affect both the trap fields and allows buildup of stray charges on the substrates via light-induced charging;
- (ii) when close to material surfaces, anomalous heating of ions may lead to rapid decoherence of their motional states;
- (iii) the need for scalable trap technology imposes severe design and fabrication constraints on the experiment.

Strong coupling criteria:
- $g = \sqrt{K + g}$
- $C = \frac{g^2}{K}$

Application:
- Fused silica substrates with alternating layers of LiF and SiO$_2$ (550 nm) cooling layer
- 0.5 mm thick glass
- Scanned interferograms measure the laser frequency profile
- ROC controlled with laser displacement
- Mirror diameter and depth controlled by laser power
- ROC varied from 300 nm to 1000 nm
- Measured surface roughness 2.8-37 Angstrom

Trapping ions above the surface of a dielectric mirror

This work:
- We present a new approach for integrating an optical cavity into an ion trap, by employing a surface electrode ion trap fabricated on top of a high reflectivity mirror. We evaluate optical losses incurred by the microfabrication, characterize trap performance, and describe plans for incorporating a second low ROC mirror to form a high finesse cavity.

Microfabrication of a surface electrode ion trap on a dielectric mirror

Fabrication of low ROC mirrors

Motivation:
- Commercial low-reflectivity mirrors (super-polished presently limited to radius of curvature (ROC) of ~25 mm)
- Dynamic damage to dielectric mirror at ~25 ppm

New approach:
- Highpower laser causes evaporation and melting of glass substrates, in turn affecting the laser frequency profile
- ROC controlled with laser displacement
- Mirror diameter and depth controlled by laser power
- ROC varied from 300 nm to 1000 nm
- Measured surface roughness 2.8-37 Angstrom

Surface micro-mirror laser characterization

Preliminary test results:
- Frequency 1-2000 MHz
- Reflected mirror scattering loss ~35 ppm
- Full 1 mm coolant
- 861 ppm (additive)

Trap + resonator: design and predicted performance

Design parameters:
- Wavelength: 4084 nm
- $R = 10000$
- $R = 1000$
- Transmission mirror 1-4000
- Transmission mirror 2-8000
- Absorption and return losses per mirror: 100ppm
- Phase 0.03
- Wavelength 0.001 mm
- Laser source
- Coating: $k = 3288$
- Return: $k_{eff} = 0.01$
- Return: 0.01

Road map

Ion trap on a high finesse mirror
- Fabrication of surface electrode ion trap on high finesse mirror while leaving aperture in electrode underneath for optical access to mirror
- Study of ion trapping ~150 mm above surface of mirror
- Post-fab mirror loss characterization
- Laser-machined low ROC mirror
- Laser machined micro-mirrors with ROC 500nm-1100 nm for micro-avity
- Cavity finesse characterization
- Future cavity + ion system

Post-fab mirror loss characterization

ROC = 1 mm mounted on pad

2.5 mm