Design and Characterization of MEMS Mirrors for Ion Trap Quantum Computation

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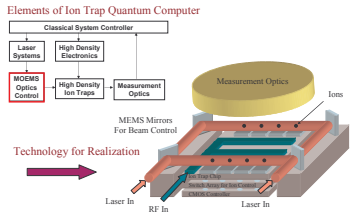
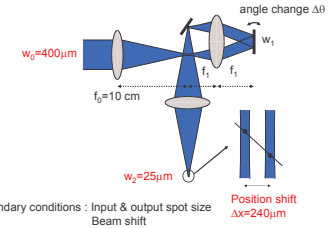
Technology for Scaling Ion Traps



J. Kim et al., Q. Inf & Comp. 5, 515 (2005).

Beam Steering for Existing Ion Traps



Boundary conditions : Input & output spot size
Beam shift
Optimization: Highest mirror speed

Designing MEMS Mirrors

Scaling Analysis

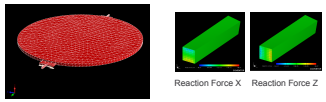
Optical Design
$w_1 \sim f_1$, $r \sim f_1$, $\Delta\theta \sim 1/r$

Device Physics
Torque (t) ~ $r^3V^2g^{-2}$

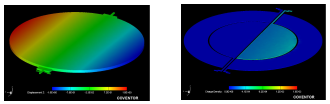
Spring Constant
$K \sim r^4V^2g^{-2}$

Resonant Freq
$f \sim V^1g^{-1}t^{-1/2}$

Numerical Simulation



Mechanical Simulation



Displacement Z Charge Density

Electromechanical Simulation

Design Results

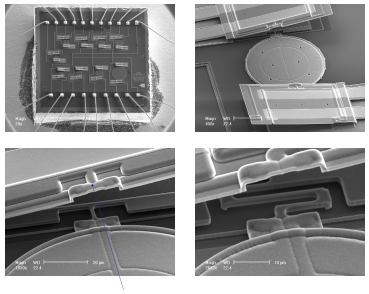
f_1 (mm)	w_1 (μm)	r (μm)	Δθ (°)	τ (N m)	K(nN m/rad)	f_{res} (kHz)	
10	40	50	0.7	2.1×10^{-11}	0.86 (0.83)	34 (33)	V=30V
				8.4×10^{-11}	3.5 (3.7)	68 (70)	V=60V
15	60	75	0.47	7.1×10^{-11}	4.4 (4.6)	34 (35)	
				2.9×10^{-10}	18 (18)	68 (68)	
20	80	100	0.35	1.7×10^{-10}	14 (14)	34 (34)	
				6.8×10^{-10}	55 (X)	68 (X)	

Device Fabrication

Foundary Process : PolyMUMPS by MEMSCAP

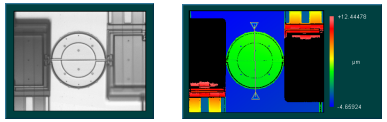
Device Release, Al Deposition, Wirebonding, Packaging : at Duke

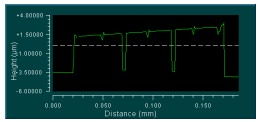
Mirror Array : Different Sizes
Operating Voltages



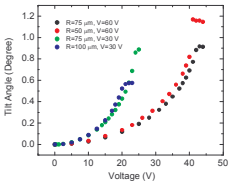
On-chip shadow mask to prevent shorts

DC Characteristics

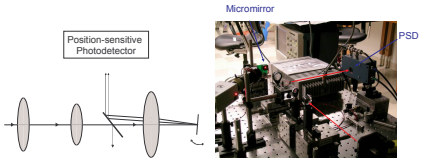


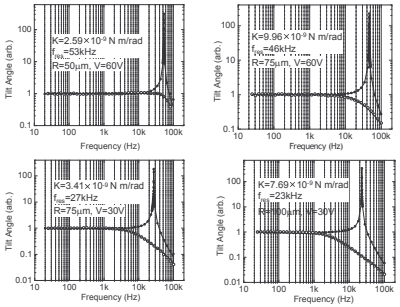


Interferometric measurements of surface profiles (Zygo New View 5000)



Frequency Response

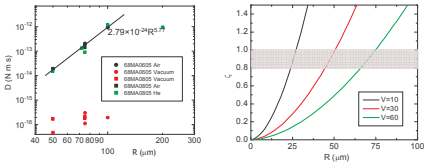




Damping Control

- Damping control → Optimum Mirror Size

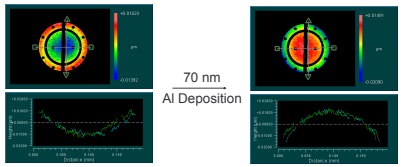
$$I\ddot{\theta} = \underbrace{\frac{1}{2}\frac{\partial C}{\partial \theta}V^2}_{U} - 2K\theta - D\dot{\theta} \rightarrow \frac{\Theta}{U} \propto \frac{1}{\omega_{res}^2 + i2\zeta\omega - \omega^2} \quad \omega_{res} = \sqrt{\frac{2K}{I}}, \ \zeta = \frac{D}{\sqrt{8KI}}$$



- Compensated Input (Open Loop)
- Feedback Control

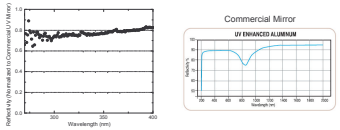
Radius of Curvature

By Interferometric measurements

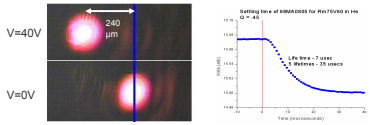


RoC: ~ - 200 mm before Al deposition
~ 140 mm after Al deposition

Reflectivity in UV

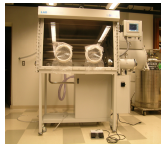


Optical Setup Demonstration



Facility at Duke

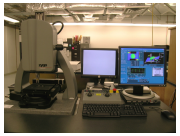
E-beam evaporator



Glovebox (Currently being installed)

West bond wire bonder

Critical Point Dryer



Optical Profiler

Flip-chip bonder (SUSS, FC150)

- Near future acquisition:
  RF Sputtering Tool for optical coatings
- Plan to acquire: Nanoimprint lithography/flip-chip bonder/mask aligner

Future Work

Mirror-Related Issues

- Improved Reflectivity
- Better Curvature Control
- Damping Control
- Tilt Angle Stability
- Power Handling Capability
- Polarization Measurement
- Incorporate into Ion Trap Experiments