Effect of Light on Ultrathin Resonators

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Introduction

MEMS and NEMS

Very Promising Devices with Very High Resolution

Application Fields

- Signal Processing
- Biological and Chemical Sensors
- Observation of Quantum Effects

Displacements Transduction

Performance Requirements:

1. Ultrahigh Displacement Sensitivity
2. Minimize Detection Back-Action

Optical Detection

Optical Techniques

- Interferometry
- Laser Beam Deflection

Advantages

1. Not Require Electrical Connection
2. Very High Resolution (10-100 $fm/Hz^{1/2}$)
3. Different Environment (*Vacuum, Gas and Liquid*)

Light Tuning

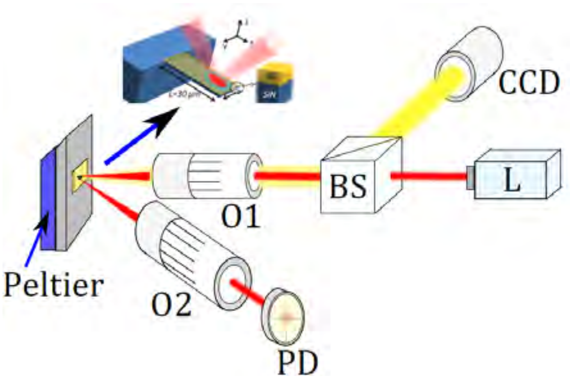
Laser Back-Action Study

1. Limit the Fundamental Detection Sensitivity
2. Take Advantage with Light Tuning

Laser Back-Action Influence

1. Microcantilever (*Volume* $\approx$ *1000* μm^3) $\Rightarrow$ Negligible Effect (*Small Effects in Vacuum*)
2. Nanocantilever (*Volume* $\approx$ *1-10*μm^3) $\Rightarrow$ Large Effects

Experimental Setup



Experimental Features

- Tunable Diode Laser
- Temperature Control
- Air Environment

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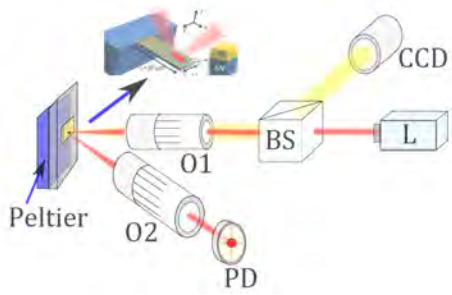

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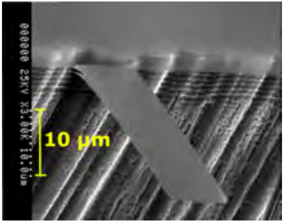
Ultrathin Bilayer Cantilever

- Substrate (SiN): 50nm
- Coating (Au): 20nm



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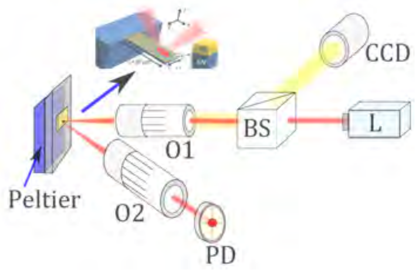

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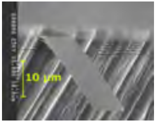

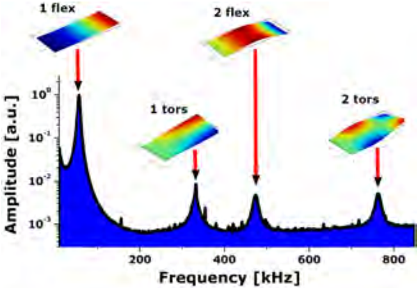

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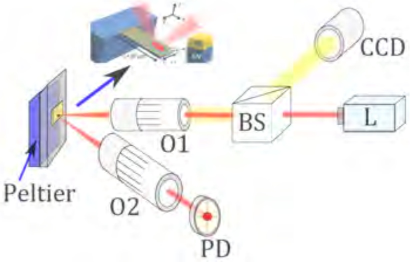

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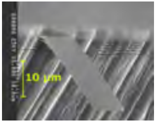
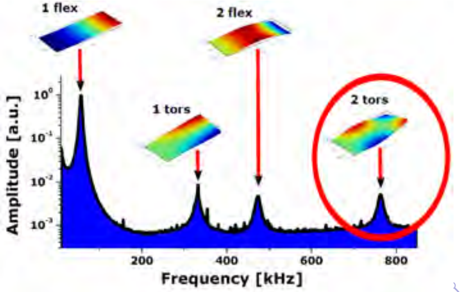
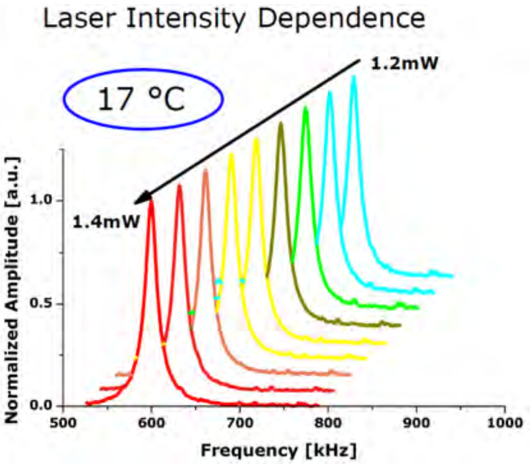
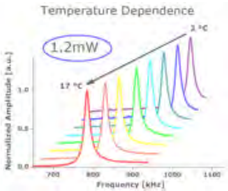




Measurements





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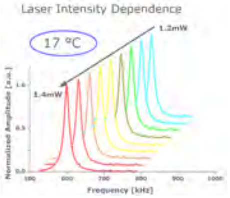

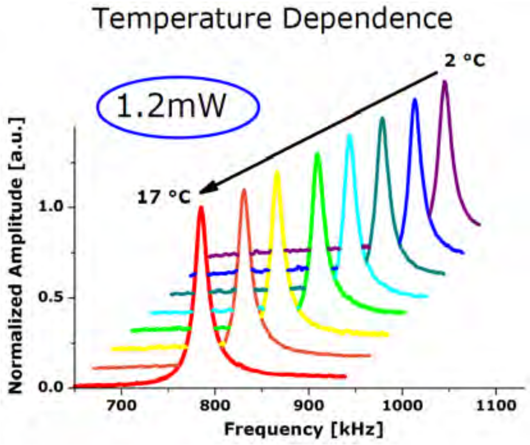

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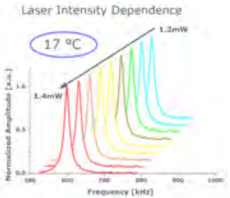
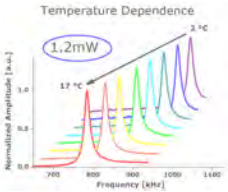
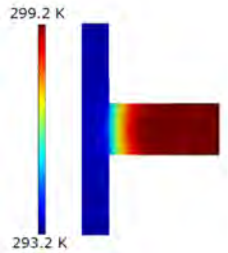




FEM Simulations → Comsol (HTM)

- $\approx 1mW$ Optical Power → Heating $10K$
- Power and Temperature Measurements are Qualitative Consistent
- **Laser Induced Heating**



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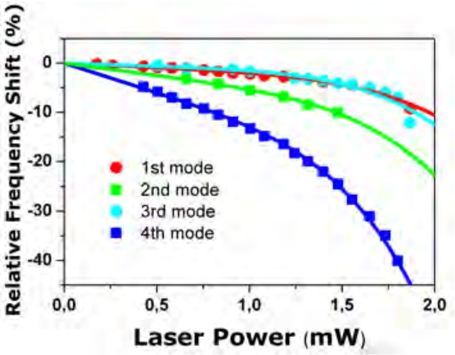
Experimental Summary



Main Features

- Non-Linear Behaviour of All Modes
- Dependence with Index Mode
- Torsional are More Sensitive than Flexural

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Theory

Doubly Clamped Resonators

Different Tuning Methods ⇒ Control of the Stress by Mechanical, Electrical and Thermal Effects

Singly Clamped Resonators: What is the Mechanism?

1. Temperature dependence of Young Modulus ⇒ Linear Effect, Negligible in Air
2. Unreleased Axial Stress ⇒ Increase in Thin Structures, Linear Effect

Theory and Simulations

3D Elastic Model with Geometric Nonlinearities

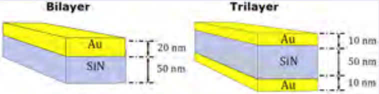
Non-linear von Karman Strain-Displacement Relations

$$\epsilon_{ij} = \frac{1}{2}\left(\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i} + \frac{\partial u_k}{\partial x_i}\frac{\partial u_k}{\partial x_j}\right)$$

- Axial Stress $\Longrightarrow N_{th} \cong \left(\frac{E_s \alpha_s h_s}{1-\nu_s} + \frac{E_f \alpha_f h_f}{1-\nu_f}\right)\Delta T$
- Moment $\Longrightarrow M_{th} \cong \frac{E_f h_f h_s}{2(1-\nu_f{}^2)}\left[\alpha_f(1+\nu_f) - \alpha_s(1+\nu_s)\right]\Delta T$

FEM Simulations $\rightarrow$ Two Different Ultrathin Structures

1. Trilayer Cantilever
   $\rightarrow$ only N_{th}
2. Bilayer Cantilever
   $\rightarrow$ M_{th} and N_{th}

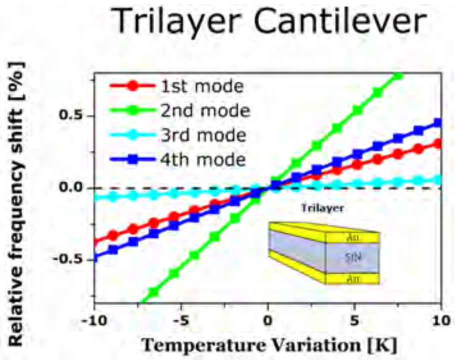


FEM Simulations

Frequency Shift Calculation: Two Sequential Steps

1. Static cantilever displacement subject to a uniform temperature change
2. Cantilever eigenfrequencies by including the static cantilever deformation

FEM Simulations



Trilayer Characteristics

- Only Axial Stress
- Linear Effect with Temperature
- Effect Quantitative Smaller Compared to our Case

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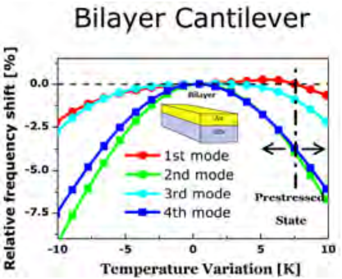
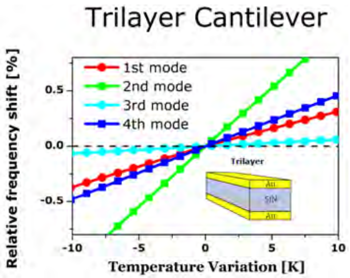
FEM Simulations





Bilayer Characteristics

- $T = 0 \Rightarrow$ Cantilever Without Thermal Strain
- Our Cantilevers are in a Prestressed State ($1\mu m$ downwards)
- Non-Linear Behaviour, Torsional are More Sensitive

Trilayer Characteristics

- Only Axial Stress
- Linear Effect with Temperature
- Effect Quantitative Smaller

Conclusion

Tuning with Laser Back-Action

1. Challenge to Achieve Fundamental Detection Limits
2. Take Advantage to Tune with Light

Frequency Shift on Ultrathin Cantilevers (50nm)

1. Non-Linear Beahaviour
2. Vibration Mode Dependent

Frequency Resonance Change

1. Unreleased Axial Stress ⇒ Residual Stress Near the Clamping
2. Bending Moment ⇒ Large Deflection

Thank You for Attention!