Indium Phosphide MEMS for Integrated Bio-Sensing

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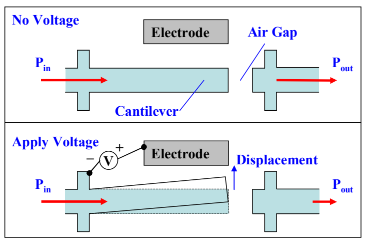
Introduction

•Microcantilevers coated with absorbing coatings are powerful tools for the detection of specific target biomolecules, gasses, vapors, or aerosols
•Measuring mechanical frequency response of cantilevers before and after the attachment of a target molecule to the cantilever can verify its presence
•Monolithically integrated sensors that require less infrastructure to operate are being explored for use in real world situations and applications
•Our sensor platform utilizes a monolithic fabrication approach involving III-V semiconductors

Optical Cantilever Sensors

Principle of Operation:

•Cantilever resonates at natural frequency
•Analyte attaches to cantilever, changing mass
•Mass change detected in resonance shift



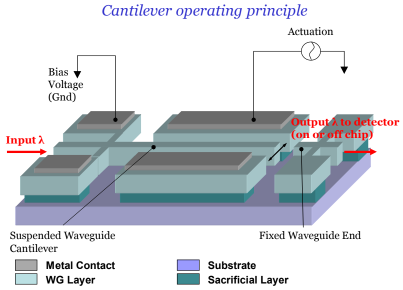
Cantilever operating principle

Optical sensing principle:

•Suspended waveguide section forms cantilever
•Fixed end couples light across gap
•Electrostatic or vibrational excitation
•Signal modulates based on optical coupling

Optical Sensing Advantages:

•**High sensitivity** to misalignment
•Increased resistance to electrical noise (compared with capacitive sensing)
•Simple control / readout electronics
•In-situ detectors and sources allow for ***full system integration***



Cantilever measurement schematic

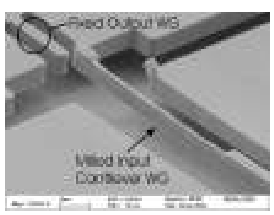
Materials/Enabling Technologies:

•Indium Phosphide, III-V materials
•Suspended Waveguides
  •InGaAs release layer (etch selective to InP)

Proof of Concept

Waveguide cantilever:

•Original resonant frequency measured
•Focused Ion Beam milling performed near tip of cantilever to change mass
•Resonance change measured
•Sensitivity of initial cantilevers
  •$\Delta m/\Delta f = 5.3\times10^{-15}$ g/Hz [1]



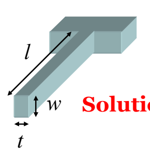
[1] M. Pruessner et al. CLEO 2005, Baltimore Md

Cantilever Sensor Improvements

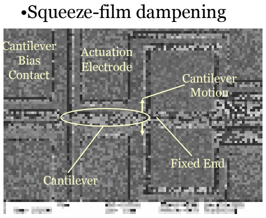
•For enhanced sensitivity, cantilever sensors need:
  •High Q factor (narrow resonance peak)
•Achieved by lowering loss mechanisms
  •Viscous drag
  •Squeeze-film dampening

$$Sensitivity \rightarrow \frac{\Delta m}{\Delta f} = \frac{2\rho \cdot wlt \cdot 0.24}{f_0 c_a}$$

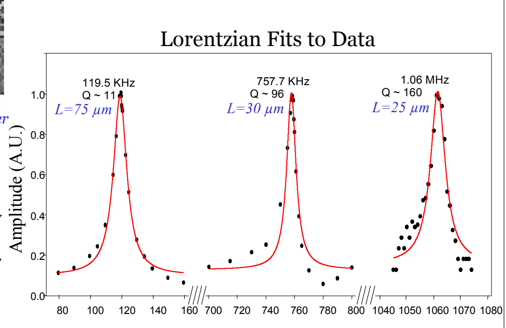
Resonant frequency



Solution → Raise cantilever resonant frequency



SEM image of high frequency cantilever



3 high frequency design cantilever resonance plots
(all 1.0 μm thick, 2.0 μm wide)

Conclusions:

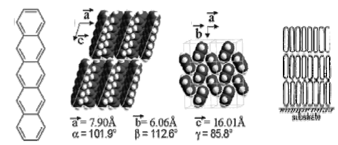
•Demonstrated device with order of magnitude increased sensitivity and Q factor
  •1.1×10^{-16} g/Hz and Q~160 for 1.06 MHz resonator in air

Functionalization Coatings

•Cantilever coatings are essential for realizing sensing operation
•Coatings must be compatible with cantilever structures
  •Dry fabrication processes (prevent cantilever stiction)
  •Must absorb/attract analyte and change mass

Pentacene

•Organic Semiconductor
•Deposition by vacuum sublimation
•Absorbs gasses and vapors within crystal layers
  •Changes semiconductor electrical properties
  •Changes mass of cantilever coating

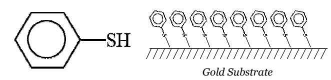


Pentacene crystal structure

Two-pronged approach to achieving selective detection: *Electrical* and *Physical* detection simultaneously

Thiols

•Self assembled organic monolayer coating
•Deposition by vacuum sublimation onto gold
•Absorbs specific molecules on surface
  •Changes mass of cantilever coating



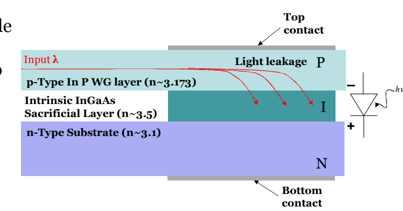
Benzene thiol and example of self assembly

Selectivity achieved through thiol chemical preparation

InP Integrated Detectors

Principle of Operation:

•Simple PIN diode configuration
•Unreleased portion of suspended waveguide forms detector's intrinsic layer
•Index mismatch in layers couples light into intrinsic absorbing region



Un-released Waveguide Section

Materials:

•Indium Phosphide waveguides
•InGaAs photoabsorbing layer

Integrated Detector Advantages:

•Ease of fabrication
•Increased efficiency of optical coupling
•In-situ detectors facilitate higher levels of ***system integration***

Future Work

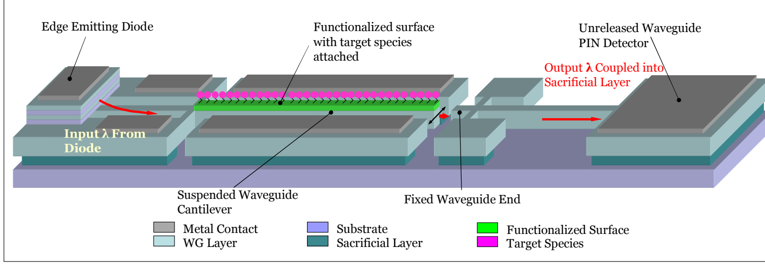
Functionalization of microcantilevers

•Verify integration of absorbing materials
•Detection of gasses, vapors, or aerosols
•Quantification of sensor response

Integrated Optical Readout

•Fabrication and characterization of integrated detectors
•Source integration: InP Light Emitting Diode

Fully Integrated Biosensor on a Chip



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