A Microfabricated Micro Gas Analysis System

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**Goal:** To create a low power, inexpensive microsystem consisting of a plasma light source and a microspectrometer that is capable of detecting air-borne contaminants with at approximately 1 ppm.

**Challenges:**
- Optimize photon generation (plasma) and collection (optics)
- High resolution of the FPI (mirror reflectivity, positioning)
- System integration and parasitic interactions
Micro Gas Analyzer Characteristics

- Operates over a wide range of pressures: ~0.1-20 Torr.
- Pressure compatible with processing system forelines or maintained with house vacuum for atmospheric pressure monitoring.
- Low power requirements, similar to power supply for cell phone, ~1W.
Micro Gas Analyzer Applications

- Environmental monitoring
  - Indoor/outdoor air contamination
  - emissions at source

- Monitoring process system products in foreline

- Monitoring of exhaust streams
Microfabricated Fabry-Perot Spectrometer

Adhesive

Upper Mirror

Actuator

Sense Electrodes

Integrated Photodiode

Substrate
Applications

- Emission Spectroscopy
- Colorimetry
- Optical filtering, communications

Operation

- Free spectral range covers visible spectrum in first order
- Higher resolving power using higher orders
- Electrostatic actuation, ~50 V, low power
- Capacitive sense electrodes for mirror spacing
- Fabrication flow allows high-reflectivity mirrors

<table>
<thead>
<tr>
<th>Cone Half Angle ($\theta_o$)</th>
<th>Increase in FWHM (nm)</th>
</tr>
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<tbody>
<tr>
<td>1°</td>
<td>0.07</td>
</tr>
<tr>
<td>2°</td>
<td>0.3</td>
</tr>
<tr>
<td>3°</td>
<td>0.7</td>
</tr>
<tr>
<td>4°</td>
<td>1.2</td>
</tr>
<tr>
<td>5°</td>
<td>1.9</td>
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</tbody>
</table>
Microspectrometer Fabrication

Fabricate Photodiode

Pattern Electrodes

Sputter deposit copper sacrificial layer

Pattern and electroplate gold cantilever beams ~ 4 microns thick

Remove sacrificial layer to release actuators, sputter deposit lower mirror employing a shadow mask.

Bond separately fabricated upper mirror
Microspectrometer
Transmitted Light at Three Spacings

\[ \lambda = 515 \text{ nm} \quad \text{FWHM} = 25\text{nm} \quad \text{RP} = 21 \]

\[ \lambda = 575\text{nm} \quad \text{FWHM} = 30\text{nm} \quad \text{RP} = 20 \]

\[ \lambda = 625\text{nm} \quad \text{FWHM} = 39\text{nm} \quad \text{RP} = 16 \]
Future Work

• Improve the resolution of the spectrometer

R=84% $\rightarrow$ R=99%
N=1 $\rightarrow$ N~3
Res.$\sim$30nm $\rightarrow$ Res.$\sim$1nm

• Integrate a photodiode on-chip
Desirable Properties for a Microplasma

- Low power/Low voltage/Low temperature
  - portable (cell phone power supply)
  - compatible with CMOS electronics
- Electrodeless
  - long life operation in reactive gases
  - “non-wetted” sensor (inert envelope)
  - reduced contamination/sputter erosion
- Small footprint and low gas volume
- Broad operating range of gas pressure
Inductively Coupled Plasma Scaling

- $45,000 \text{ cm}^3$
- 1 kW @ 2 MHz
- $d = 500 \text{ mm}$
- $p = 0.01 \text{ Torr}$

- $0.17 \text{ cm}^3$
- 1 W @ 490 MHz
- $d = 5 \text{ mm}$
- $p = 1 \text{ Torr}$

$p d = \text{ constant}$
Microfabricated ICP

Hybrid package
Glass wafer
Interdigitated capacitor
5 mm coil
Microfabrication Process

- PR
- Cr/Au/TiW Glass Wafer
- Expose/Develop
- TiW etch
- Electroplate Gold
- PR strip
- TiW/Au/Cr etch
- Bond to 10 mm diam. glass chamber
- Spiral coil
- Interdigitated capacitor
- To vacuum system

SEM of Interdigitated Capacitor Structure with 10 micron thick Au
Emission Spectrum of SO$_2$ in Ar

(Argon emission is subtracted)

Intensity (counts)

Wavelength (Angstroms)

196 ppm
873 ppm
4736 ppm

SO$_2^*$

S

Ar

O?
Detection Limit of SO\textsubscript{2} in Ar

Microgas Analyzer Performance Benchmark

Ongoing optimization has achieved 200 ppb.

Detection Limit of SO\textsubscript{2} in Ar

Experimental data

Linear Regression

99% Confidence Bands

3-sigma Detection Noise

\( \text{S}_{\text{peak intensity}} \)

1 ppm

\( \text{SO}_2 \) fraction, ppm
Proposed Work

- Develop ambient gas sensors for cleanroom and wafer environments
- Develop effluent gas sensors for detection of reactor products (foreline, scrubber, exhaust)
- Develop process gas impurity detectors
- Optimize microgas analyzer, 200→1 ppb
- Evaluate sensitivity to H₂O, fluorocarbons.
Water vapor detection

SO$_2$ spectrum (32 ppm in Ar) with water contamination

Intensity / arb. unit

$\lambda$ / Å

OH
SO$_2^*$
Ar (subtracted)
S

Plasma Engineering Laboratory

Northeastern University