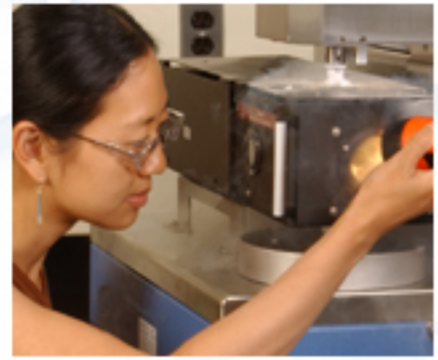




Silicon nanowire mass sensors

Brian A. Bryce, Jason J. Gorman, Sergiy Krylyuk, and Albert Davydov

NIST
National Institute of Standards and Technology
U.S. Department of Commerce

MATERIAL MEASUREMENT LABORATORY

Outline

- Introduction to vapor-liquid-solid nanowire growth
- Literature nanomechanical measurement of mass
- Our idea
- Experimental Results
- Questions

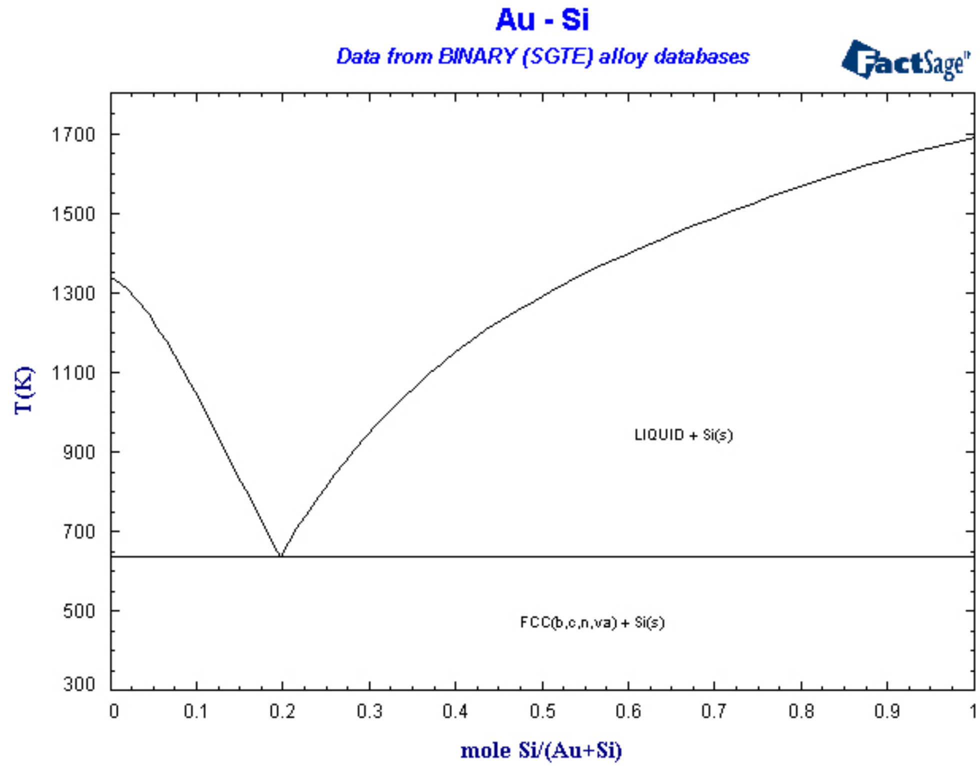
Vapor-liquid-solid nanowire growth

In 1964, R. S. Wagner and W. C. Ellis first observed the growth of silicon crystals from Au particles due to the presence of a silicon vapor.

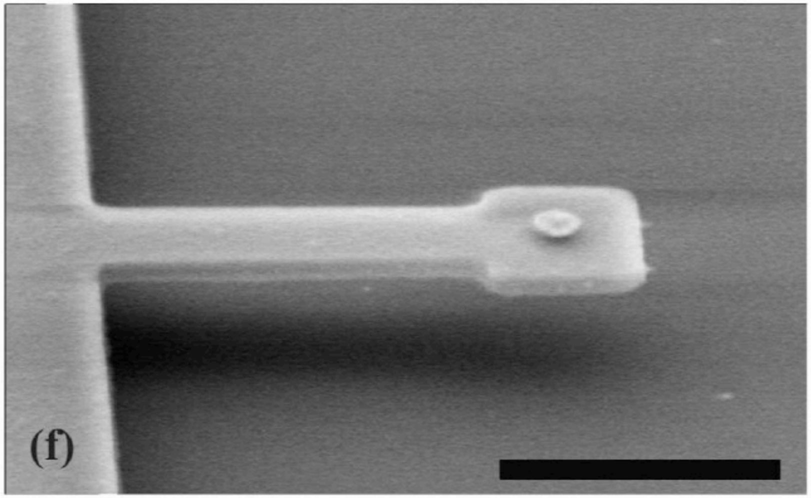
The wires were solid, the particle was a liquid eutectic and the precursor was a vapor so they called the method: vapor-liquid-solid (VLS) growth.

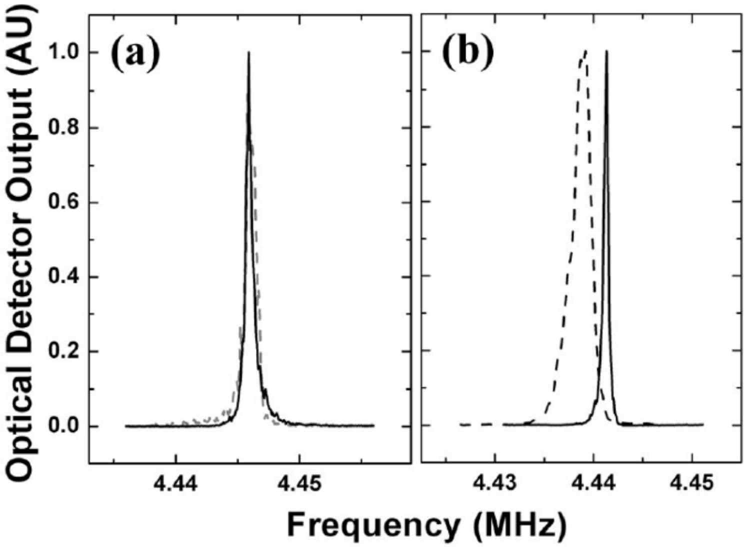
It depends on the eutectic point of a binary phase diagram.

VLS growth was originally called whisker growth in the 1970s following Wagner and Ellis's work but eventually evolved in the 1990s into nanowire growth, capable of creating rods at nanoscale dimensions.



Attogram detection using nanoelectromechanical oscillators





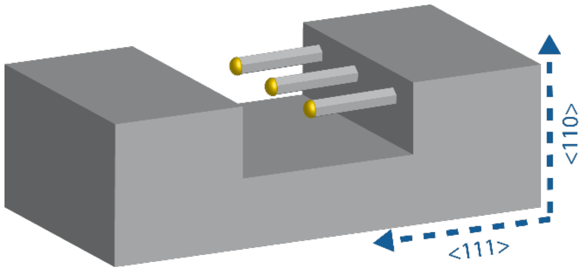
Resolvable mass = 0.39 ag

$$f_0 = \frac{(\beta l)^2}{2\pi} \frac{t}{l^2} \sqrt{\frac{E}{12\rho\,(1+4\gamma)}}$$

$$\gamma = \frac{m}{\rho A l}$$

B. Ilic, H. G. Craighead, S. Krylov, W. Senaratne, C. Ober, and P. Neuzil, *J. Appl. Phys.* **95**, 3694 (2004).

Nanowire cantilevers for mass based sensing



Idea: Use site *controlled* growth of Si vapor-liquid-solid wires to create high sensitivity mass sensing platform

Tapered regular hexagon with end mass:

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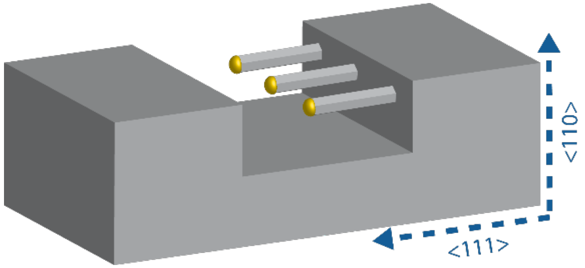

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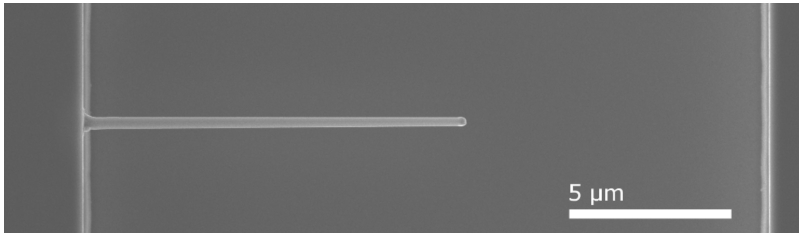
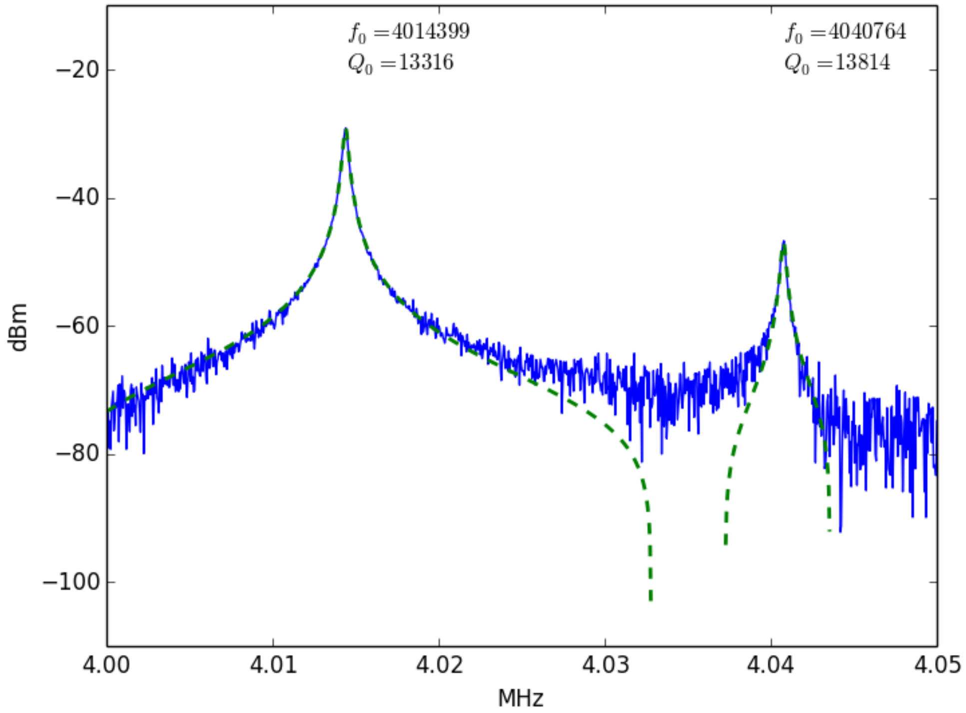


Reality

$$Q > 13000$$

$$\sigma_f = 0.5 - 1\ Hz$$

Estimated resolvable mass = 0.07-0.14 ag



Questions?

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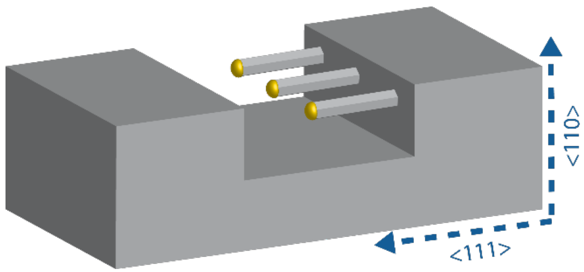

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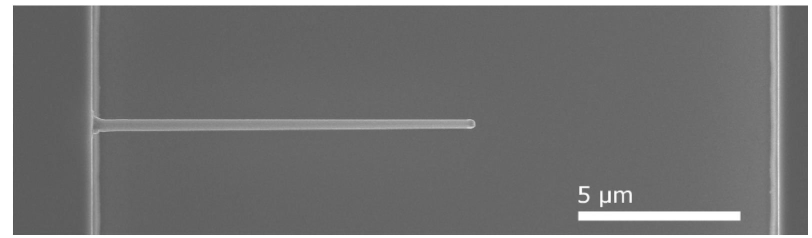

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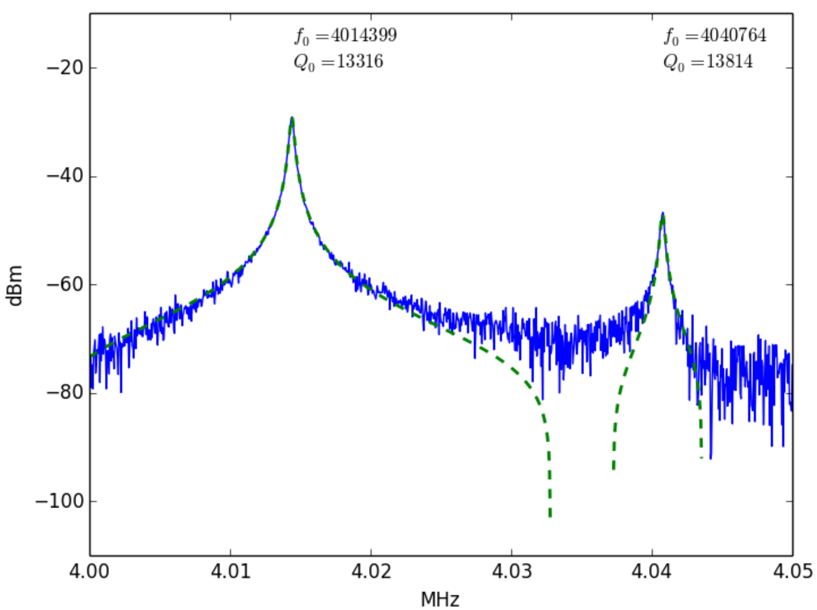

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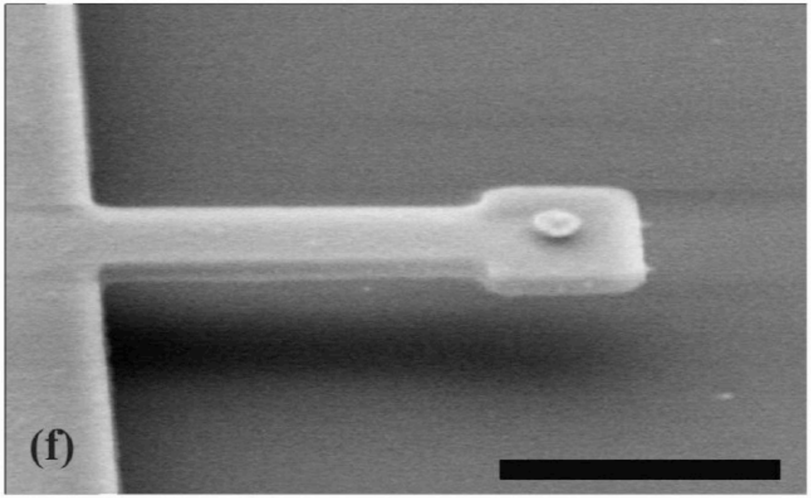

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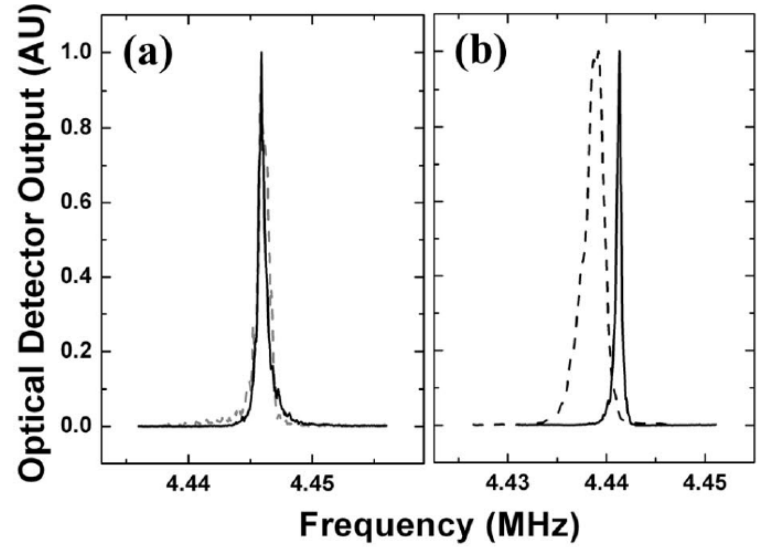

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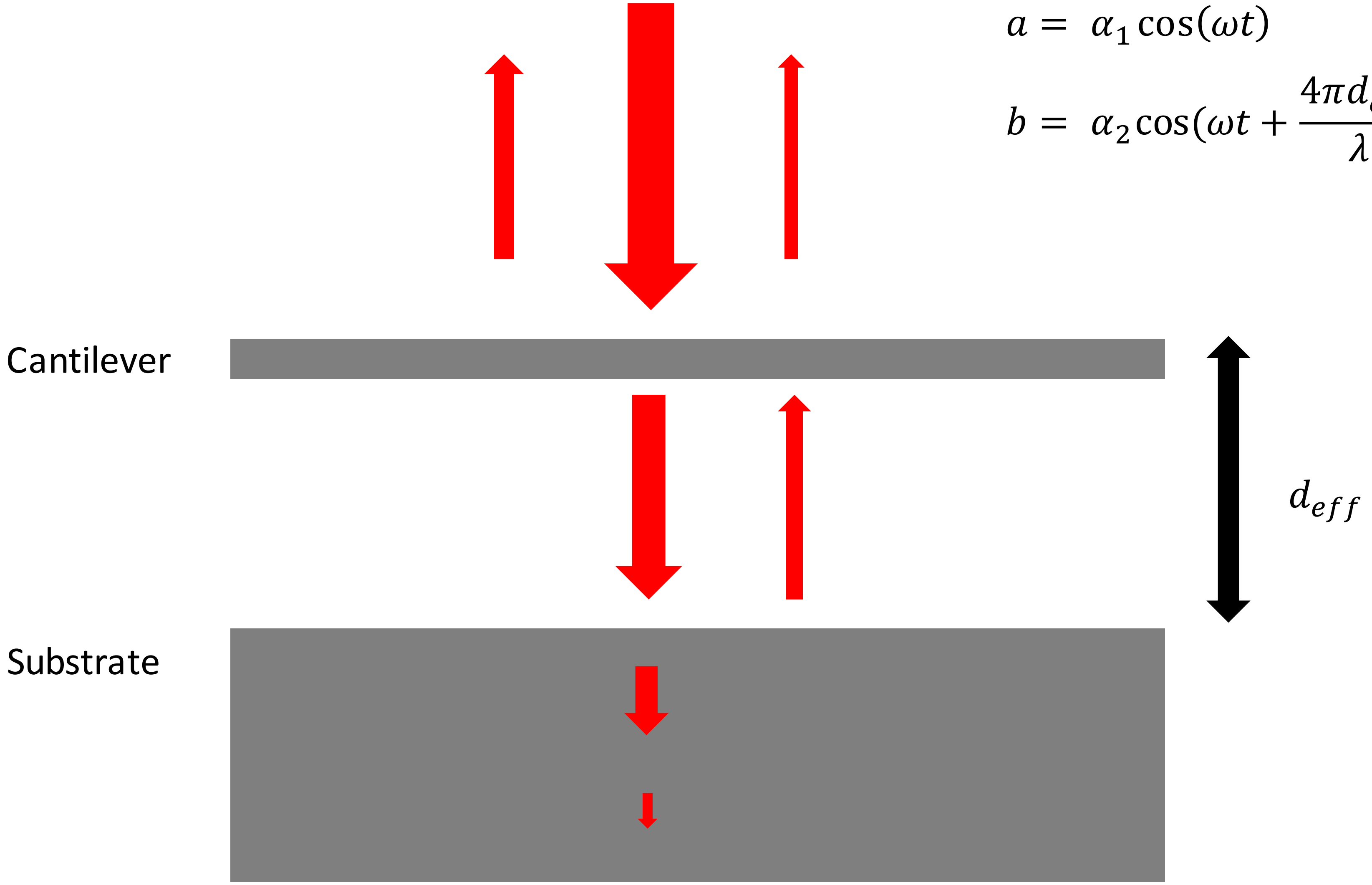
Measurement principle - Fabry–Pérot interferometer

$$a = \alpha_1 \cos(\omega t)$$

$$b = \alpha_2 \cos(\omega t + \frac{4\pi d_{eff}}{\lambda})$$



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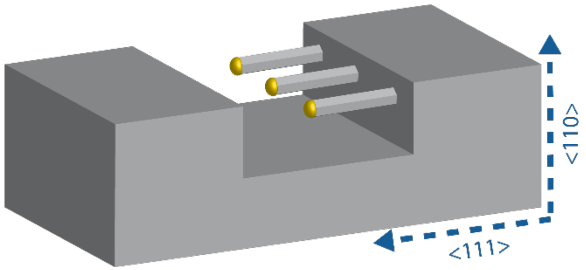

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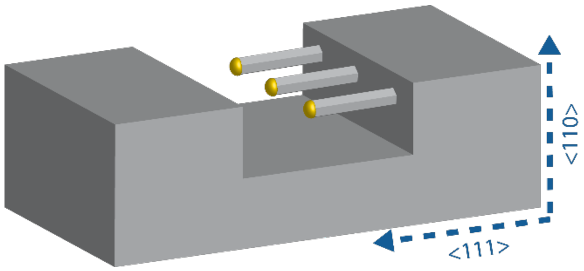
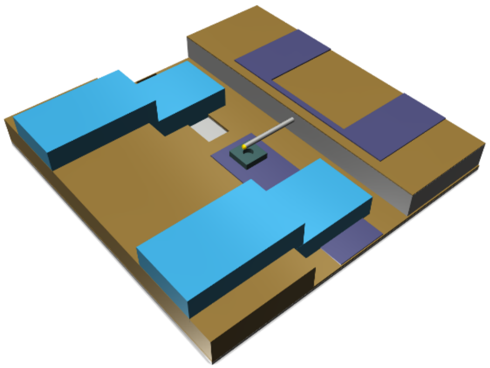
- Highly integrated sensor is an interesting metrology system-on-a-module problem

Goal:

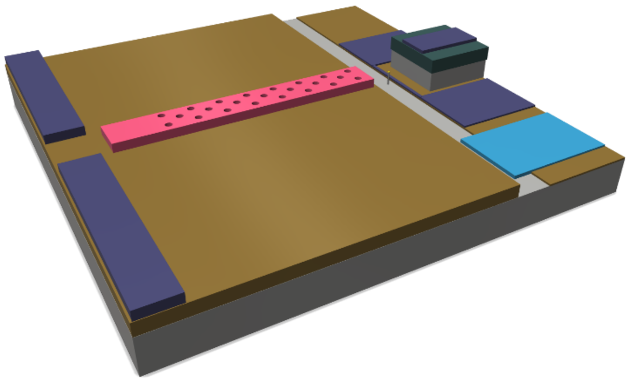
One chip and PCB with same measurement quality as entire lab of equipment

Phase 1: Show site controlled growth on sidewalls of high-Q VLS cantilevers, and estimate mass sensitivity





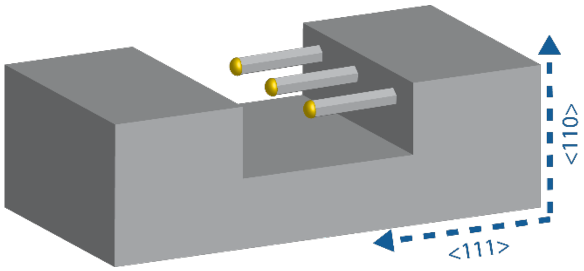
Phase 2: Integrate photodetector, and thermal driver to allow for partial multiplexing



Phase 3: Integrate light source for full multiplexing

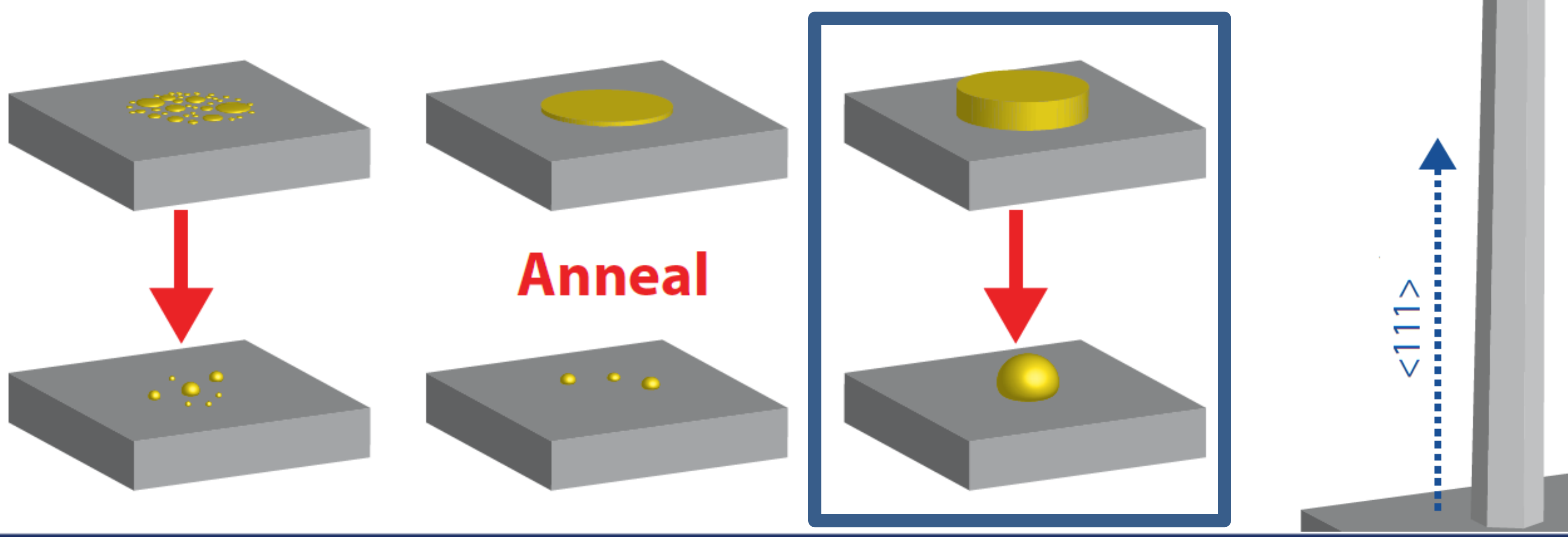
Phase 4: Integrate vacuum pump to complete high resolution mass detection system

Phase 1: Show site controlled growth on sidewalls of high-Q VLS cantilevers, and estimate mass sensitivity

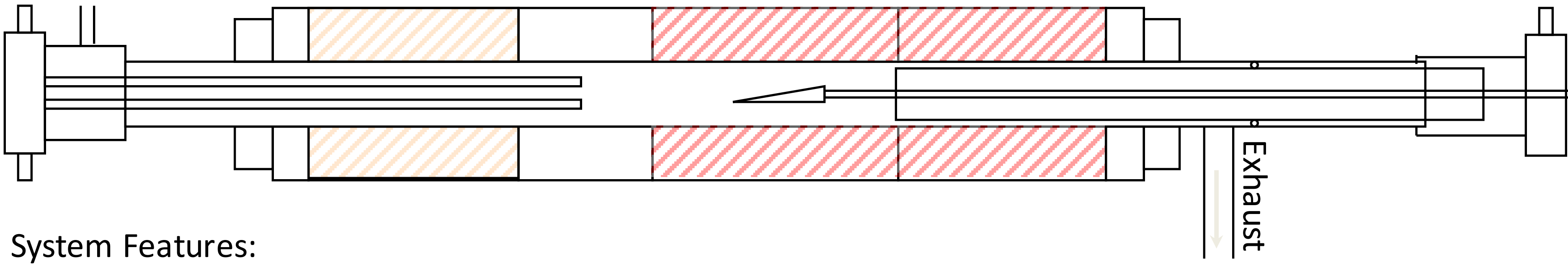


Control is needed

1) Grow a wire where we want
2) Grow it in a particular direction
3) Grow *one* wire

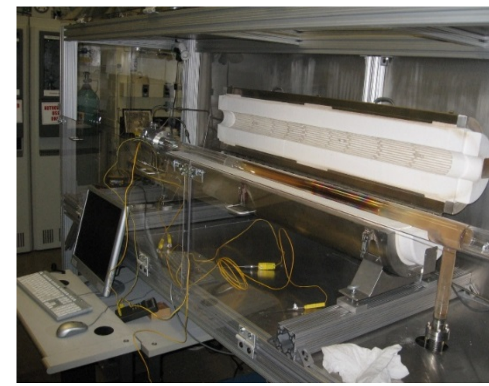


Nanowire reactor



System Features:

- ❑ 4-zone furnace; quartz reactor for 2” wafers
- ❑ Variable pressure (3 mTorr – 760 Torr) with N_2/H_2 carrier gas
- ❑ SiH_4 and $SiCl_4$ precursors
- ❑ *In situ* doping for n- (PH_3) and p- (BCl_3) types



Si NWs growth conditions:

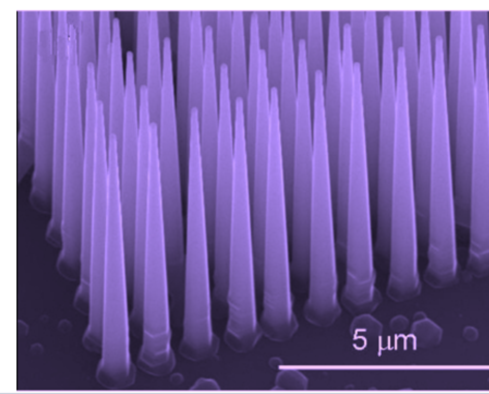
T_{growth} = 500 -- 1050 C → 900C

P = 10 -- 760 Torr → 600 Torr

Growth rate = 0.1 -- 10 um/min

$$SiH_4^{v} \xrightarrow[\text{10-600 torr}]{\text{400-650C}} Si^{s}$$

$$SiCl_4^{v} \xrightarrow{\text{900C}} Si^{s}$$



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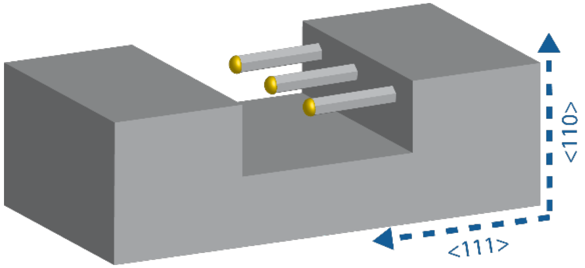

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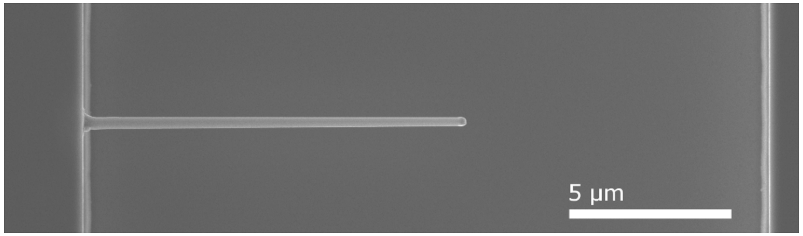
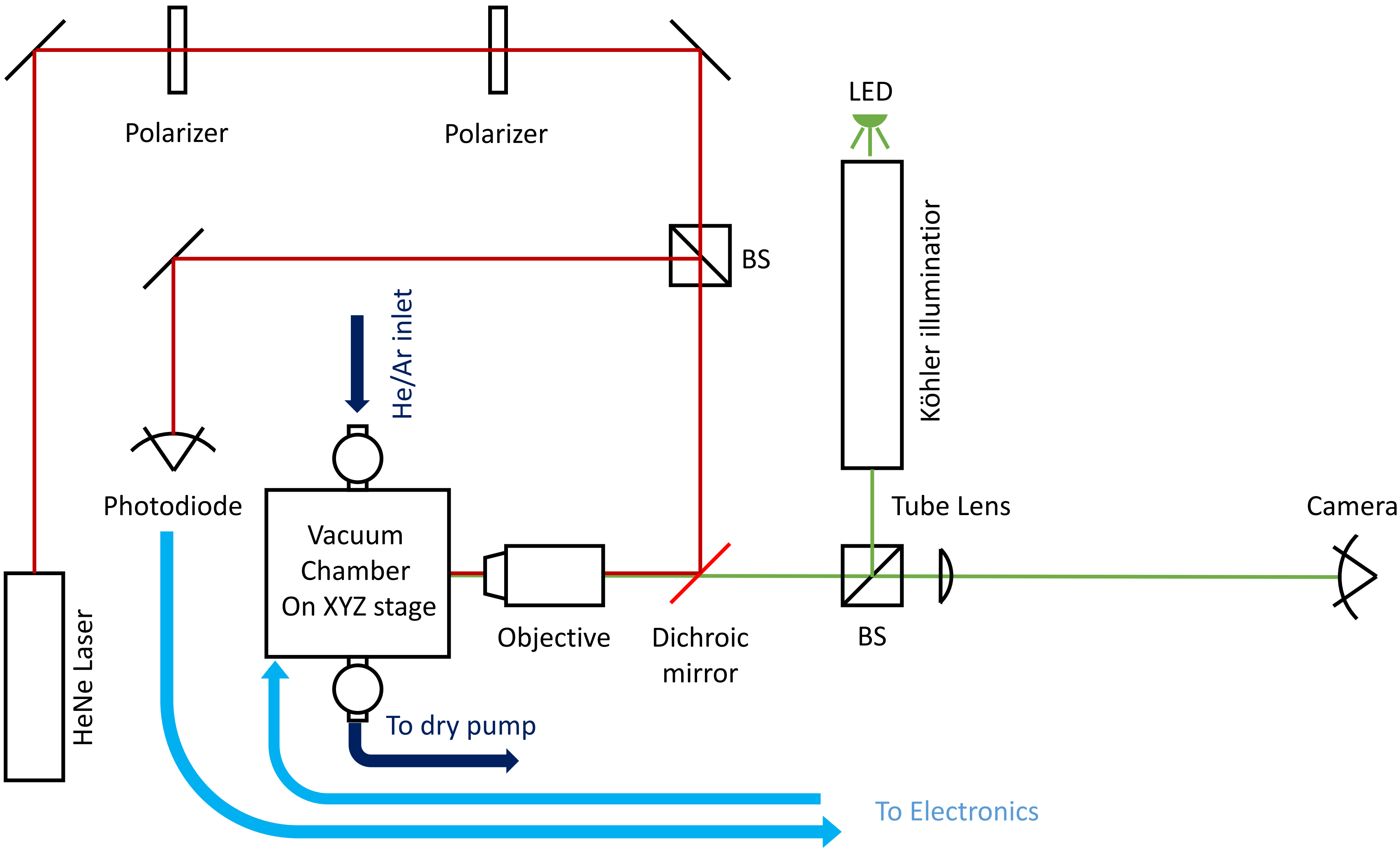


Reality

The instrument (Phase 1)



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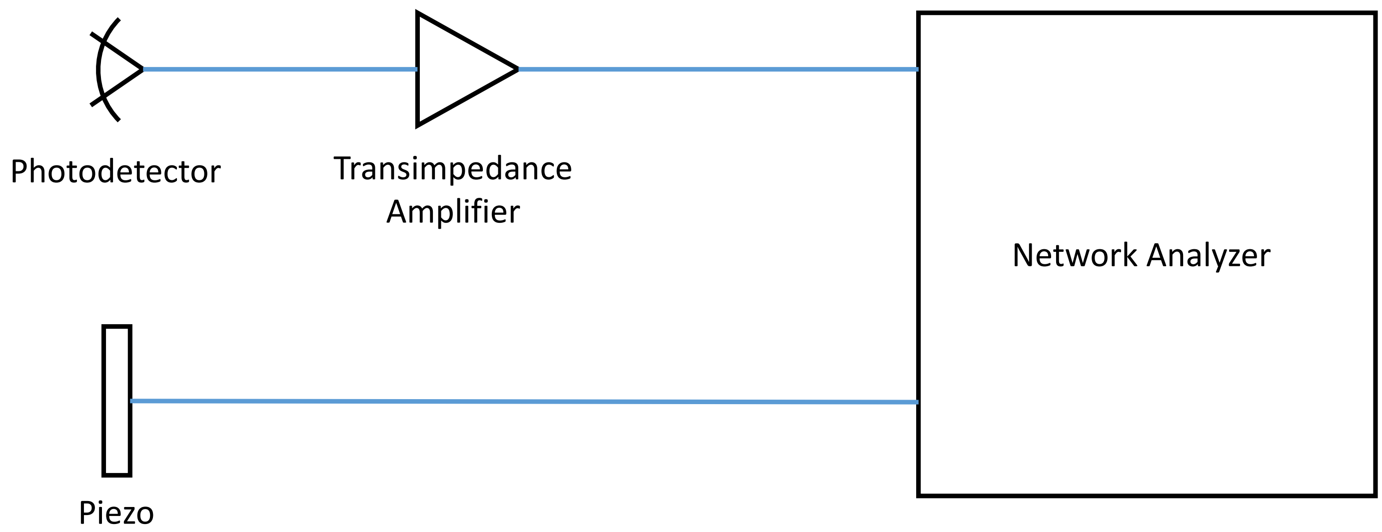

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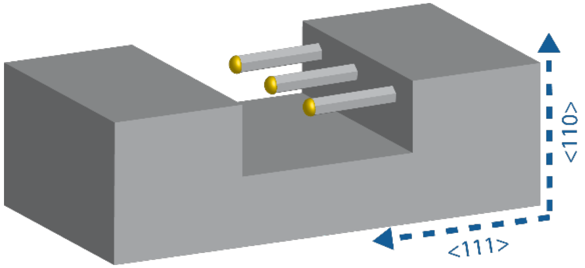

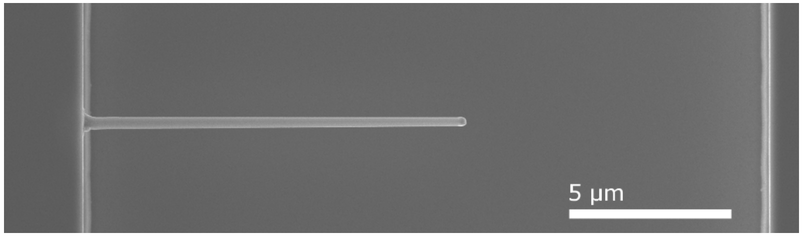

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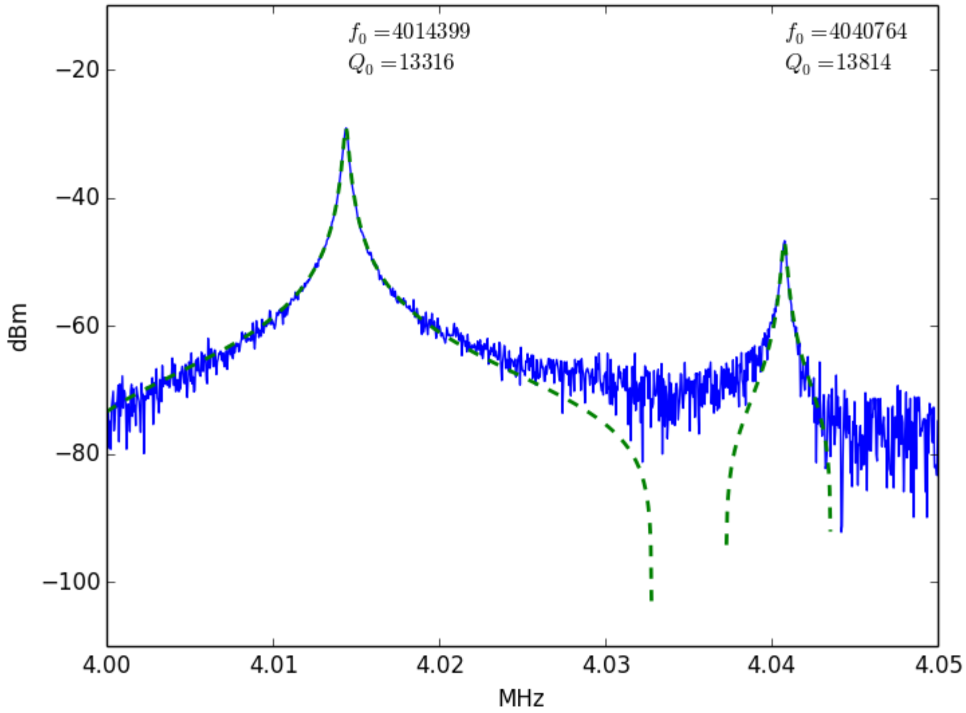
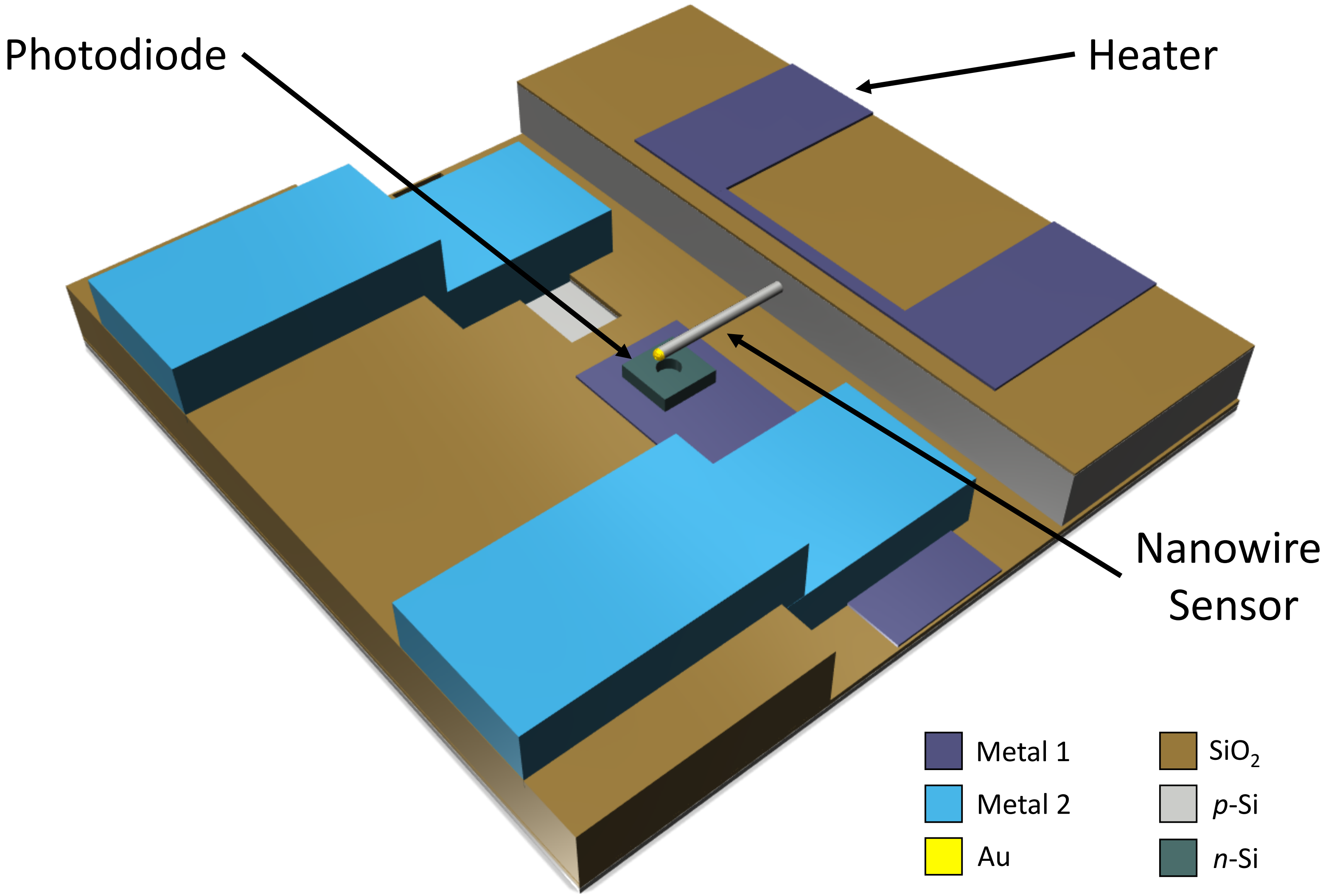
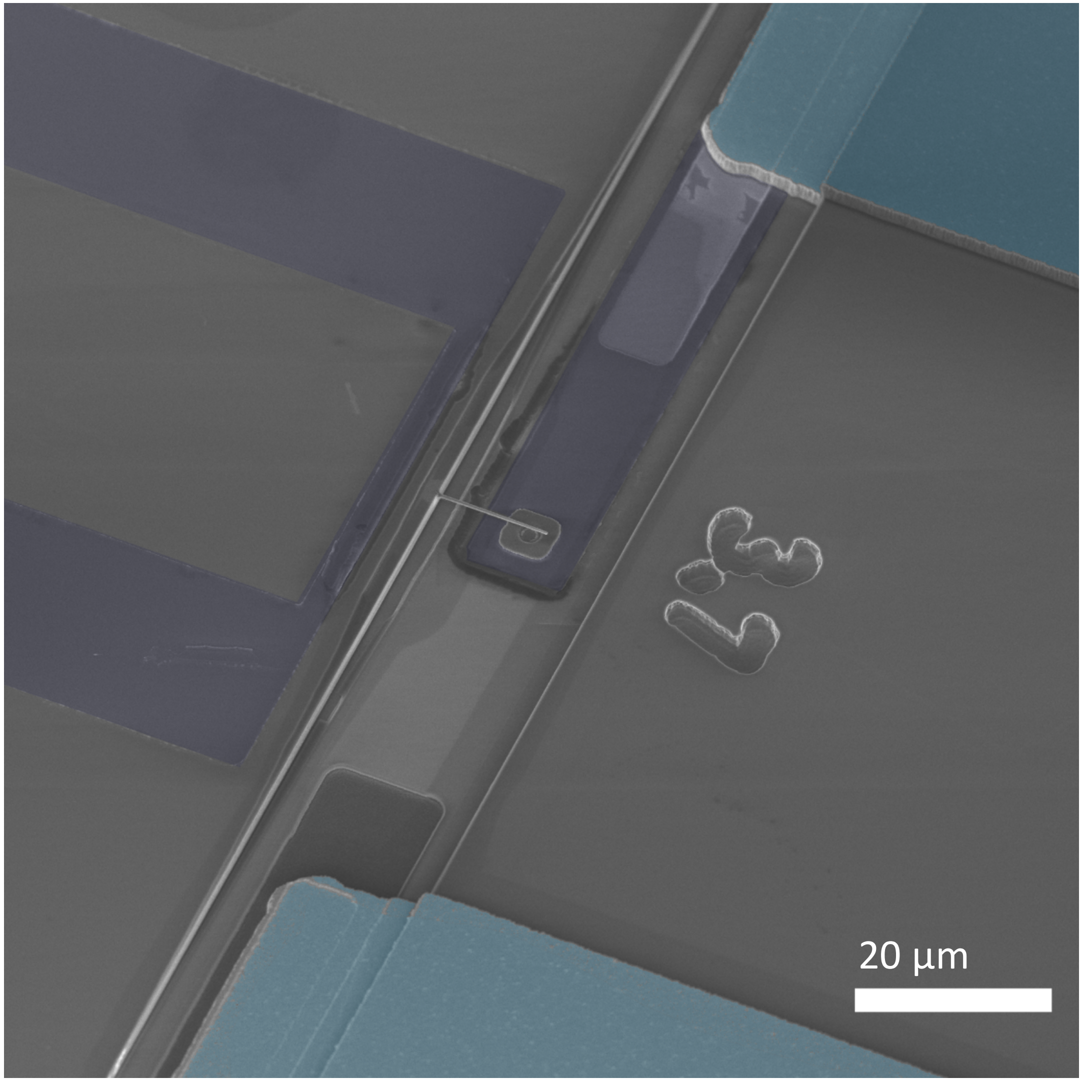
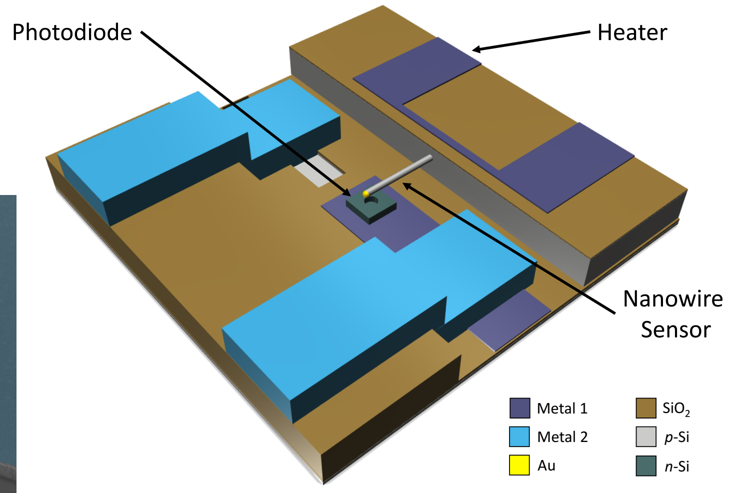


Phase 2 device design



Phase 2 device reality





10 layers of lithography!

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2. Oxidize (RCA + tube)
3. Trench definition (L + RIE + KOH)
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5. VIA for diode (L + RIE + HF)
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9. M0 Liftoff (L + evaporation)
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11. VIA through SiNx (L + RIE)
12. Window open (L + HF)
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14. Wire growth
15. Contacts (L + HF + evaporation)

Use your title slide effectively:

- Core message
- Get people to want to listen

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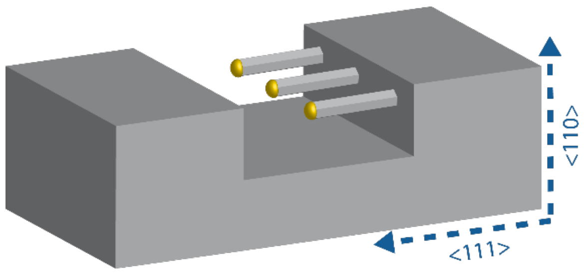

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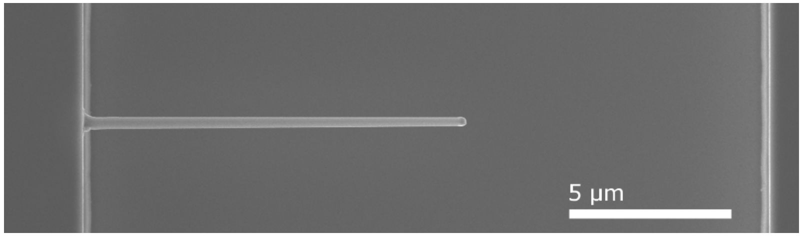

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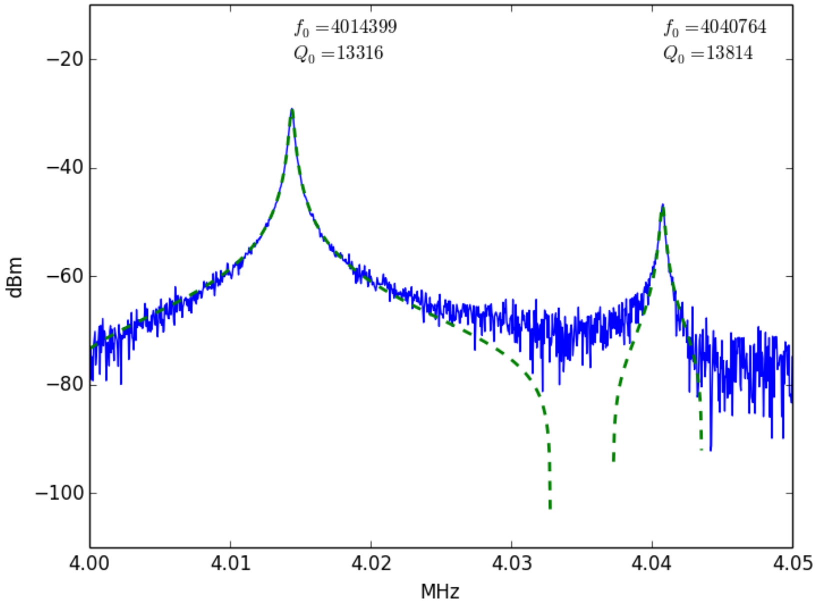

Better than 0.14 attogram sensitivity

(0.00000000000000000014 g)

Outlines waste time*

* Exception for talks longer than 1 hour or super formal settings

Outline

- Introduction to vapor-liquid-solid nanowire growth
- Literature nanomechanical measurement of mass
- Our idea
- Experimental Results
- Questions

Keep text to minimum

Text heavy slides are generally bad

Vapor-liquid-solid nanowire growth

In 1964, R. S. Wagner and W. C. Ellis first observed the growth of silicon crystals from Au particles due to the presence of a silicon vapor.

The wires were solid, the particle was a liquid eutectic and the precursor was a vapor so they called the method: vapor-liquid-solid (VLS) growth.

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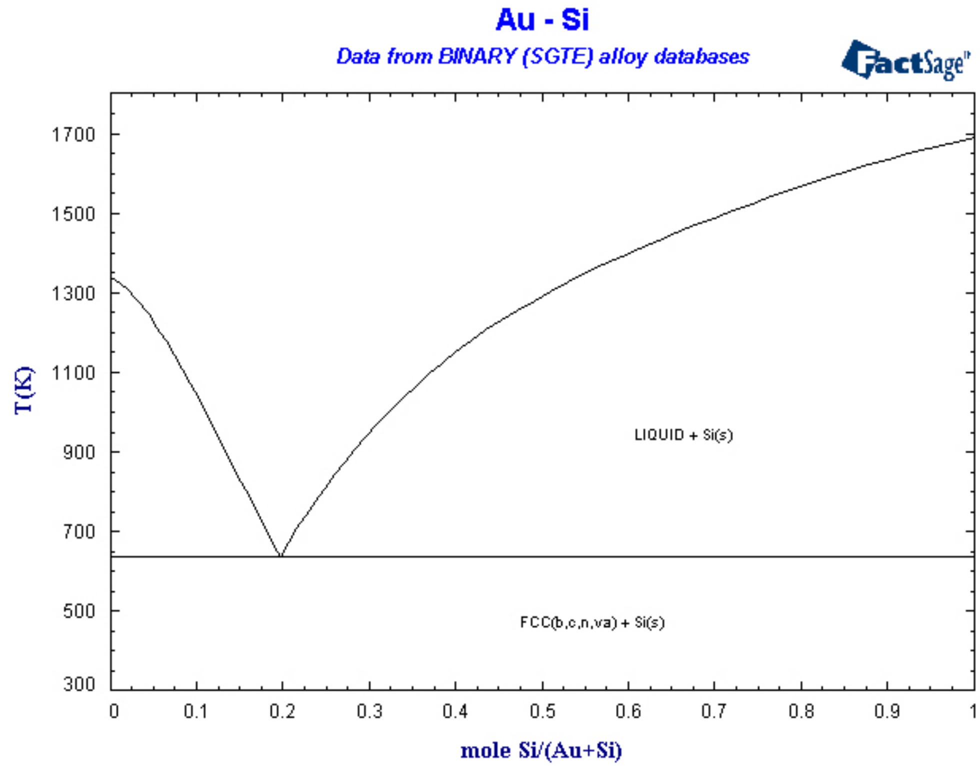
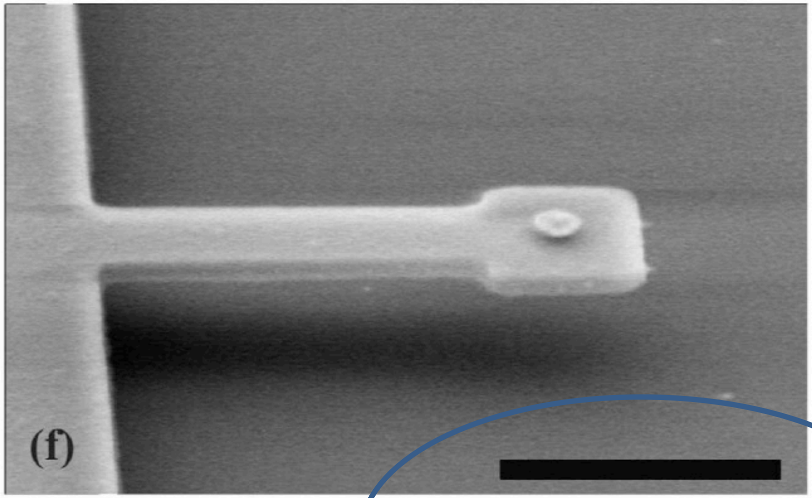


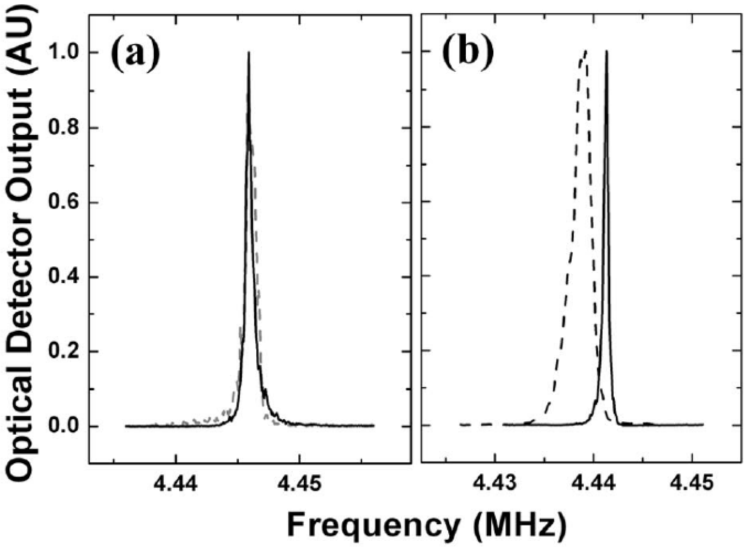
Label things clearly

Make fonts large enough to read

Attogram detection using nanoelectromechanical oscillators



No scale



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Too small

B. Ilic, H. G. Craighead, S. Krylov, W. Senaratne, C. Ober, and P. Neuzil, *J. Appl. Phys.* **95**, 3694 (2004).

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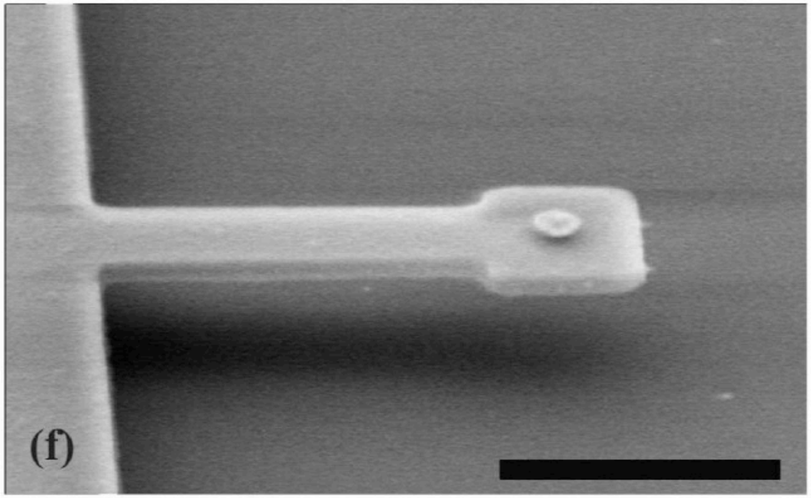

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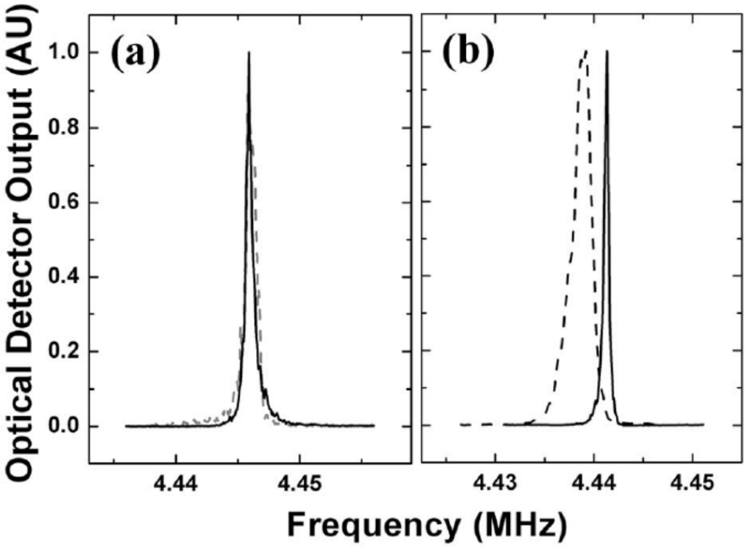

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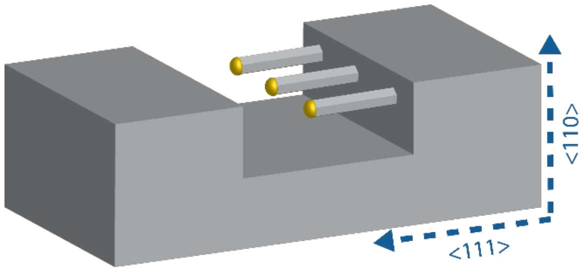
Clearly explain why you have made design choices

Nanowire cantilevers for mass based sensing



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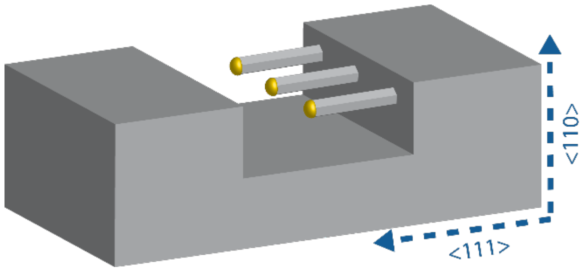

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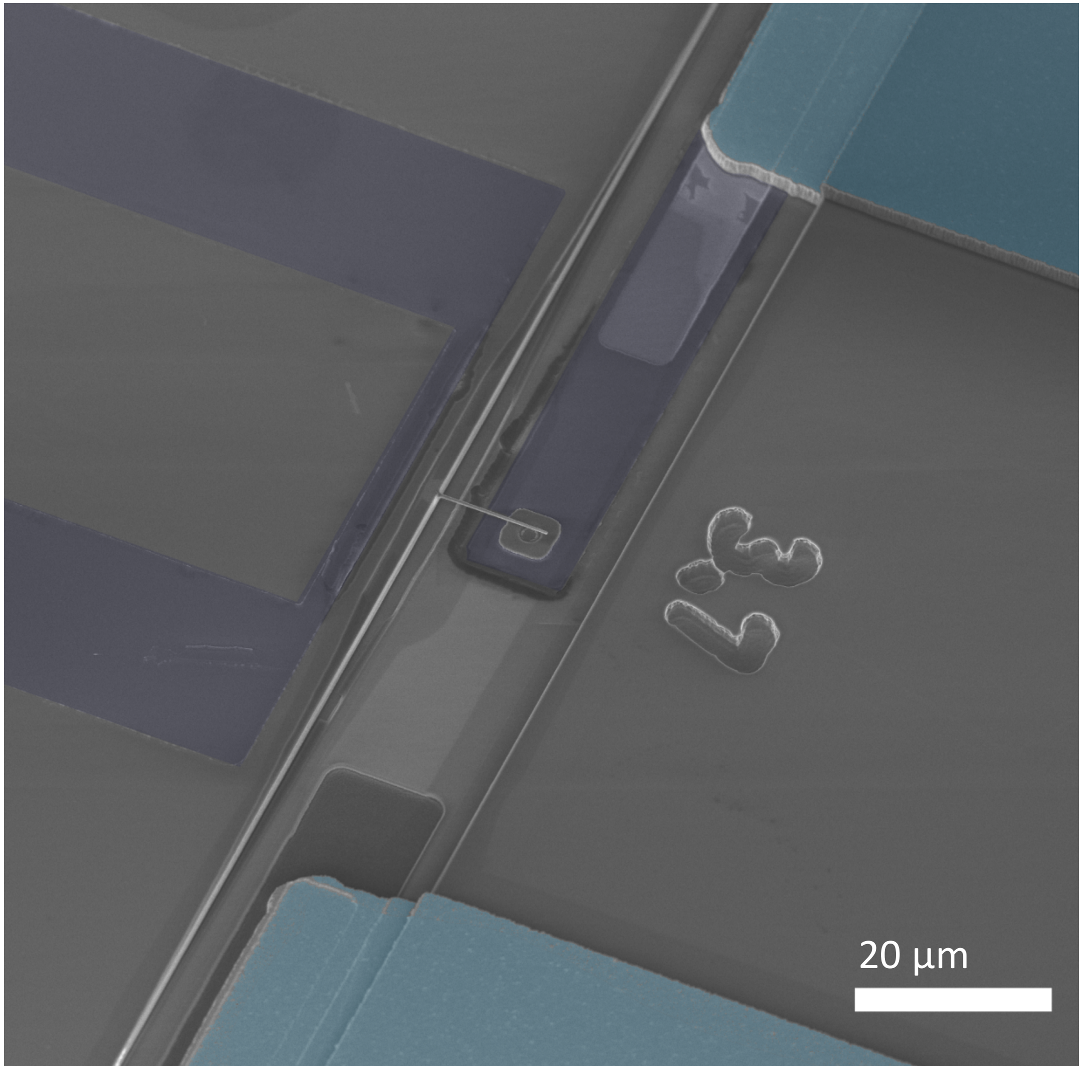
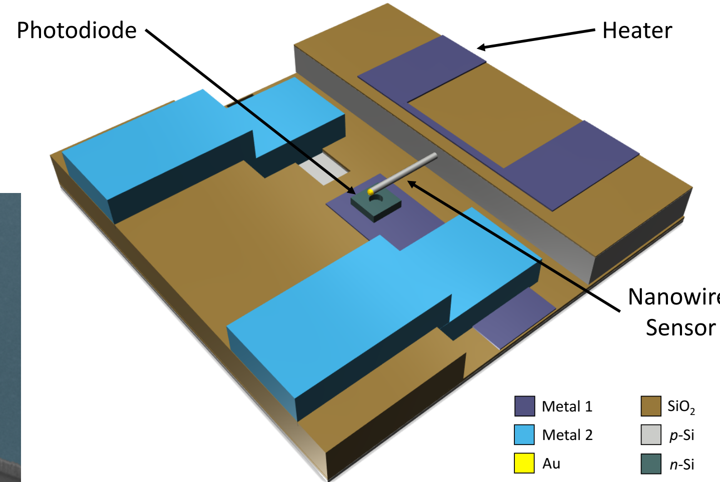
End with the message you want *remembered* or something to make people talk to you after

Questions?

Phase 2 device reality





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General advice:

- You can expect your audience to retain 2-3 things in a 15 minute talk
- Know your audience: what interests them, what do they know, what do they not know