Principles of Electronic Nanobiosensors

Unit 1: Introduction to Nanobiosensors

Lecture 1.3: Basic Concepts: Types of Biosensors

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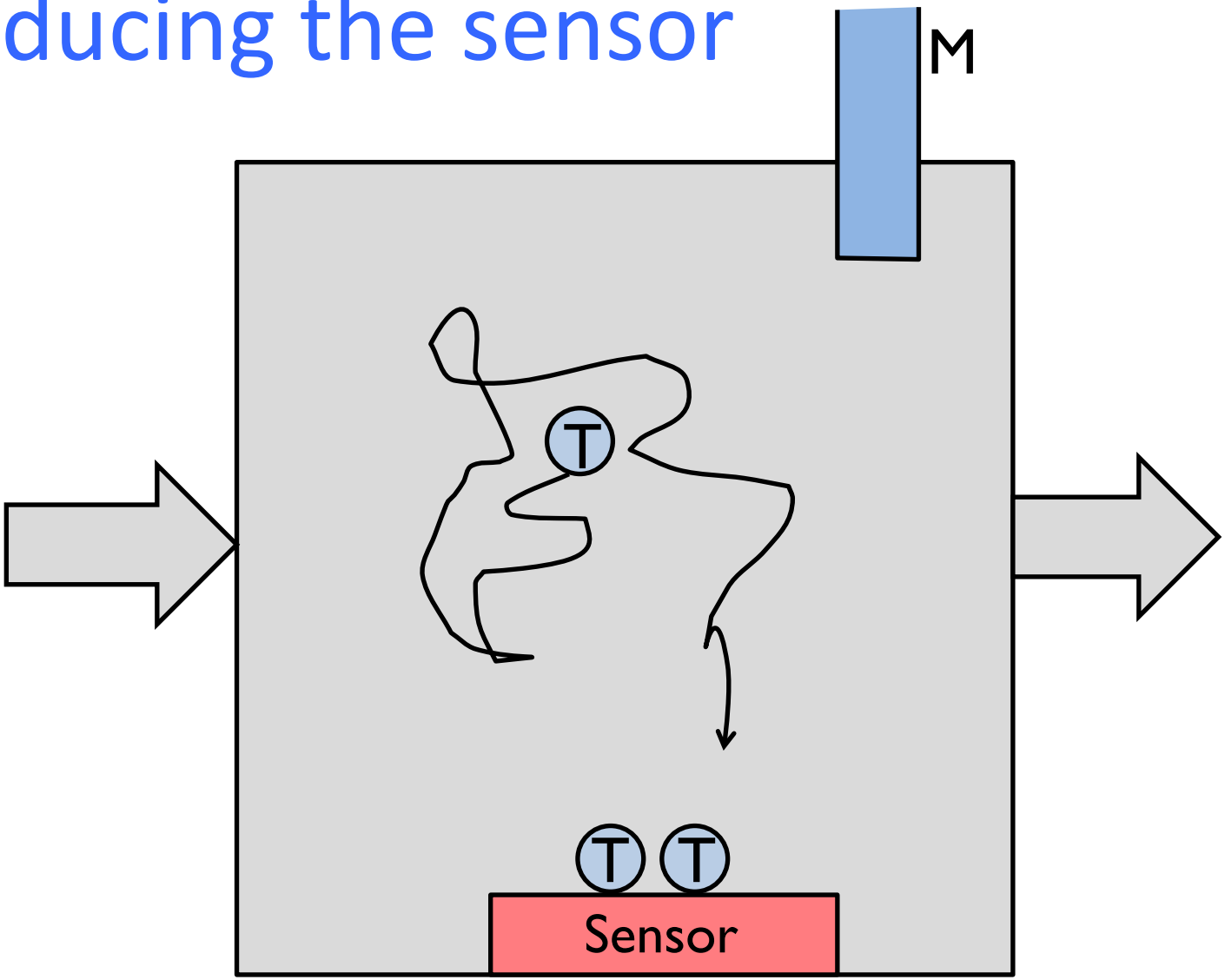
Outline

- Definition of terms continued …
- Types of sensors – mechanism of transduction
- Geometry as a variable for high sensitivity
- Summary and conclusion

Introducing the sensor



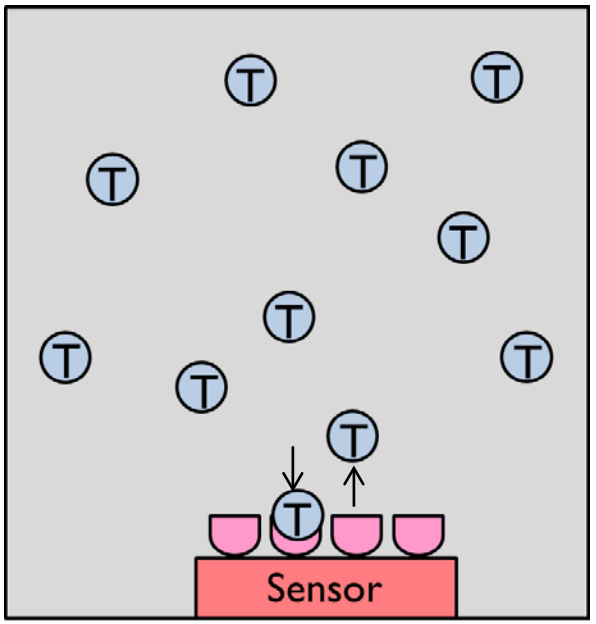
Capture of molecules on sensor surface

$$\frac{dN}{dt} = k_F (N_0 - N)\rho_s - k_R N$$

$$N(t) = N_{ss}(1 - e^{-(k_F \rho_s + k_R)t})$$

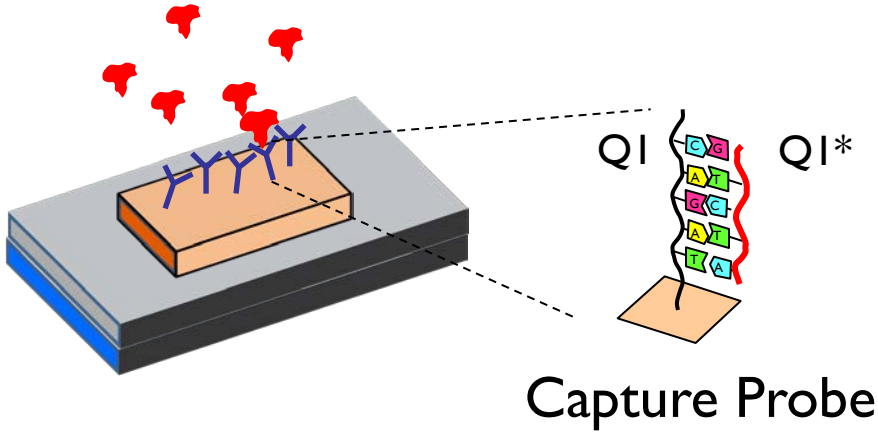
$$N_{ss} = \frac{k_F \rho_s}{k_F \rho_s + k_R} N_0$$

$$k_F \to \infty, \rho_s \to 0$$



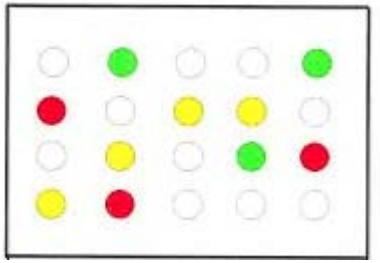
Alam, Principles of Nanobiosensors, 2013

Nanoscale biosensors: Labeled approach

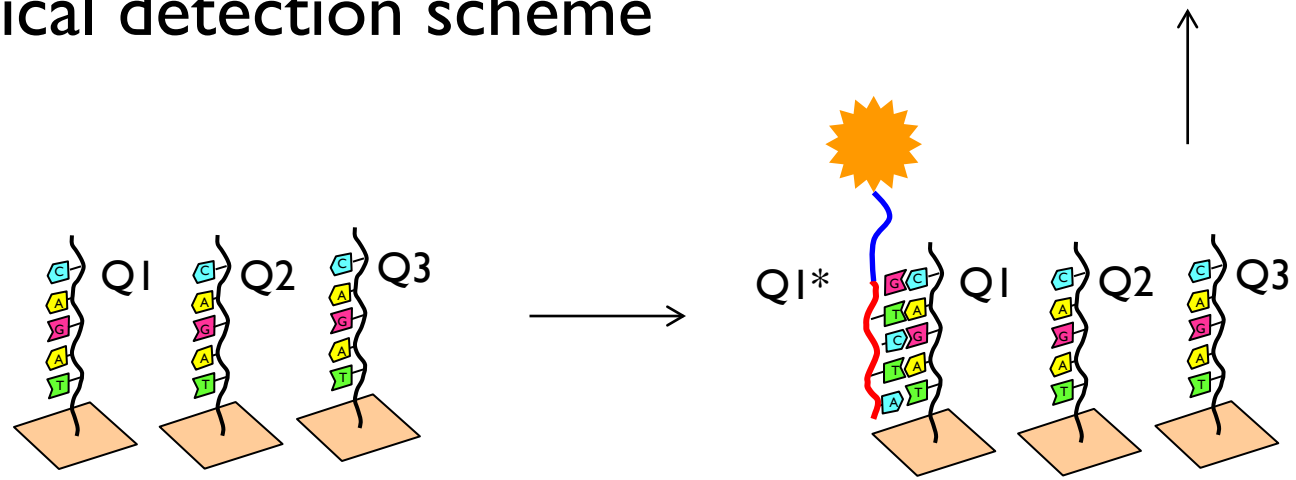


DNA Microarray, DNA chip

Imaging



Optical detection scheme



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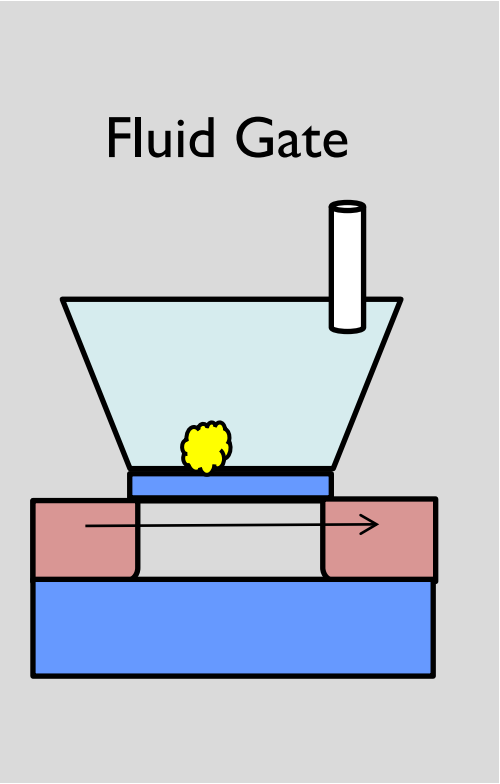
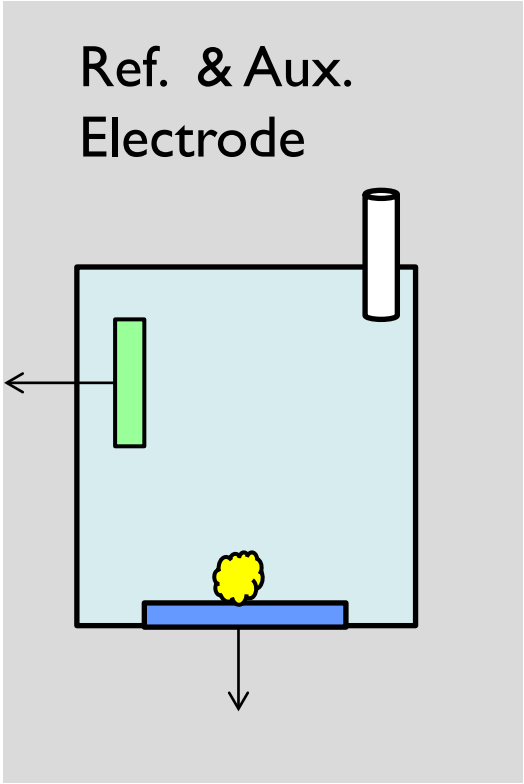
Three types of label-free sensors

Potentiometric



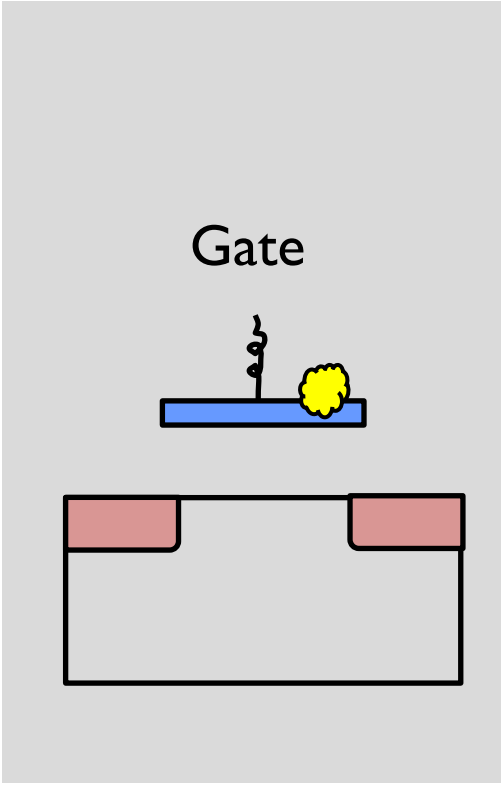
Charge to current

Amperometric



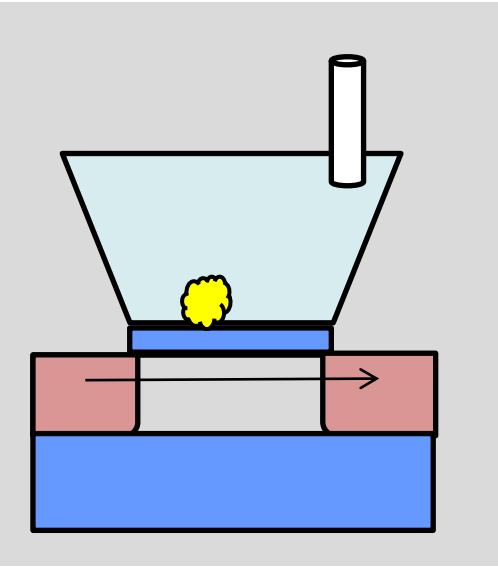
Chemical to current

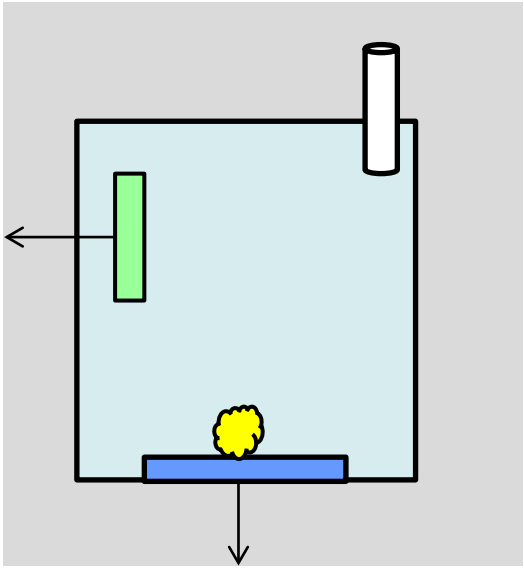
Cantilever

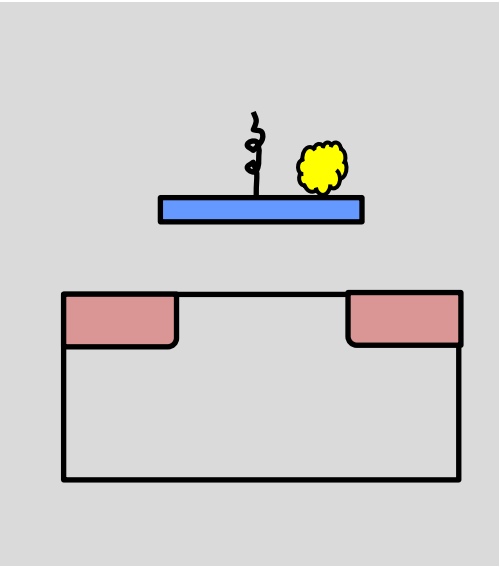


Mass to frequency

Sensitivity are similar







$$S \sim \begin{bmatrix} N_s \\ \ln N_s \end{bmatrix}$$

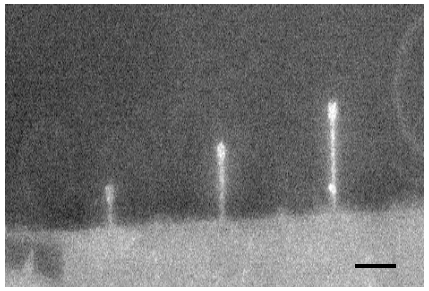
$$S \sim \begin{bmatrix} N_s \\ \sqrt{N_s} \end{bmatrix}$$

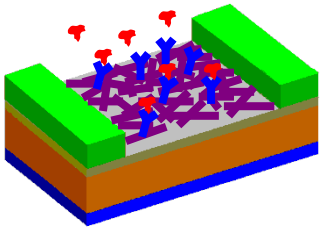
$$S \sim \begin{bmatrix} N_s \\ \ln N_s \end{bmatrix}$$

Analogy to camera … similar megapixels!

Diversity of biosensors

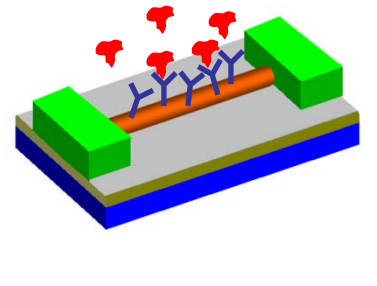
Nano Cantilever (~pM)



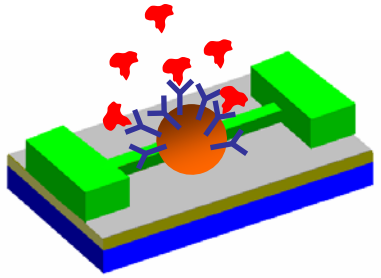


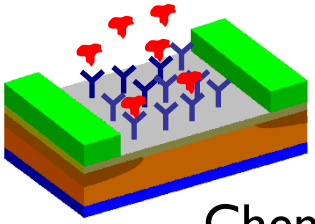
Nano-Net (nM-pM)

Si-NW/CNT (nM-aM)



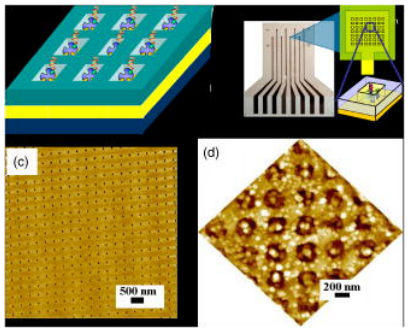
Nanodots

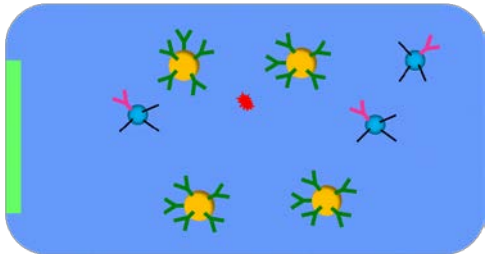




ChemFET/IsFET (~mM)

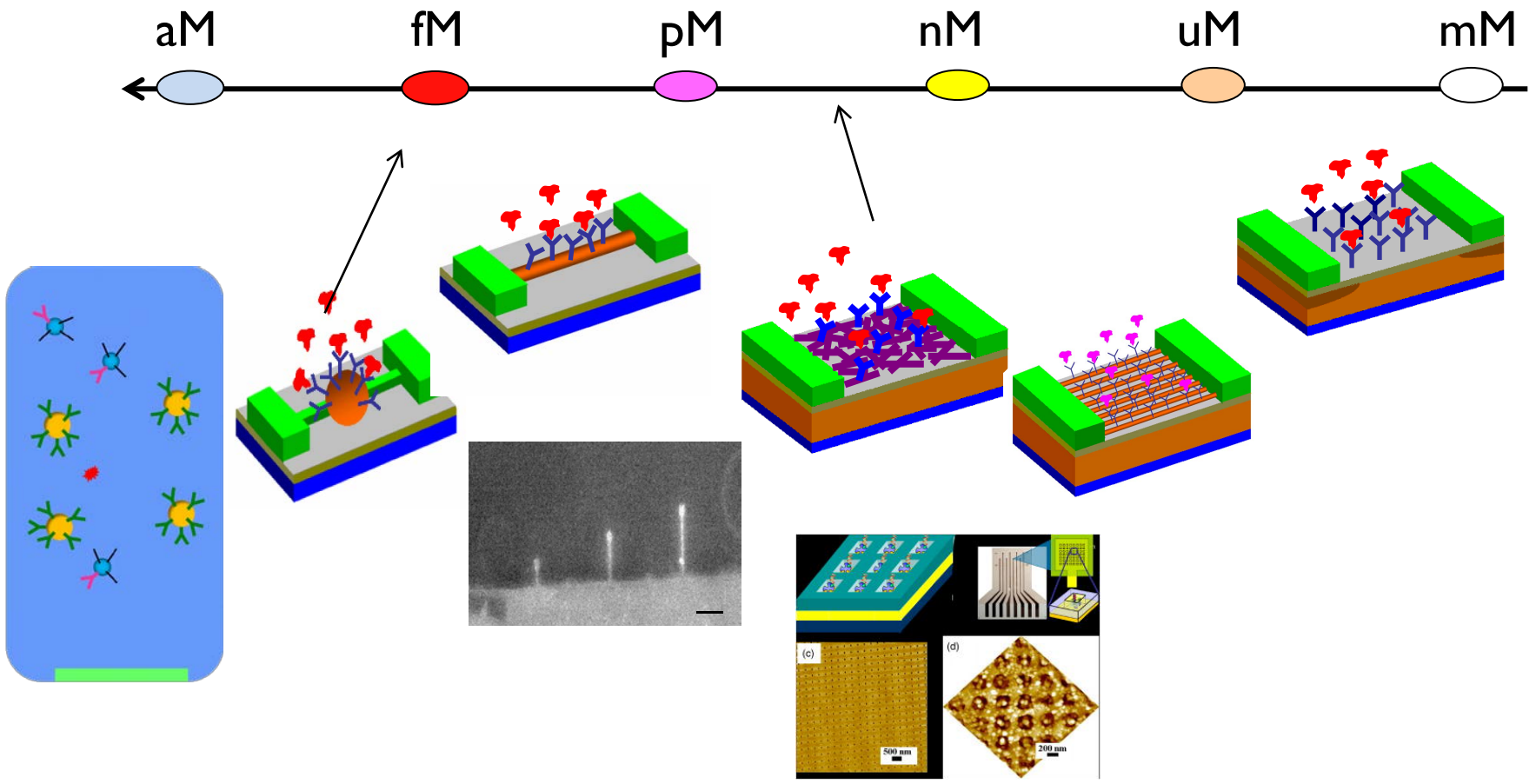
Array sensors (~pM)





Biobarcode (~aM)

Nanobiosensors have high sensitivity



Is there something fundamental about the geometry?

Sensitivity Gain: Geometry of Electrostatics ?

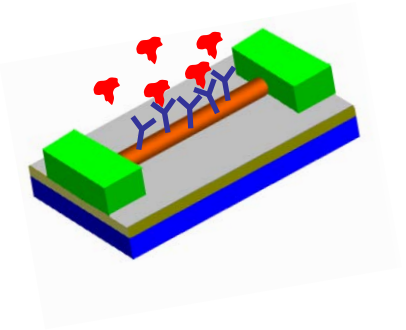
$$I_b = qN_D \times \pi R_b^{\,2} \times \upsilon$$

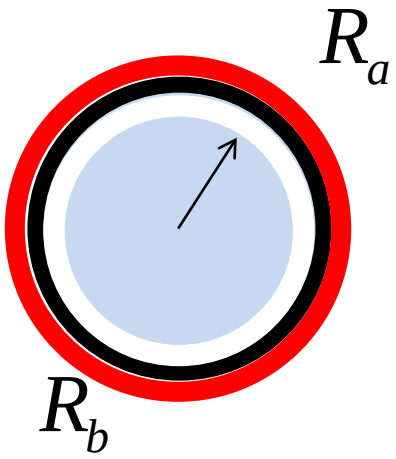
$$I_a = qN_D \times \pi R_a^{\,2} \times \upsilon$$

$$Q_{bio} = 2\pi R \times qN_{bio}$$
$$= qN_D(\pi R_b^{\,2} - \pi R_a^{\,2})$$

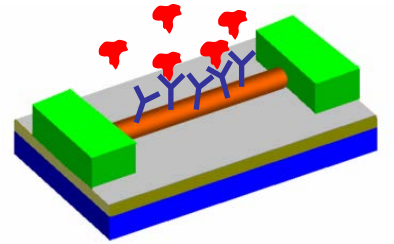
$$S \equiv (I_a - I_b)/I_b$$

$$S \sim \frac{2N_{bio}}{N_D R}$$

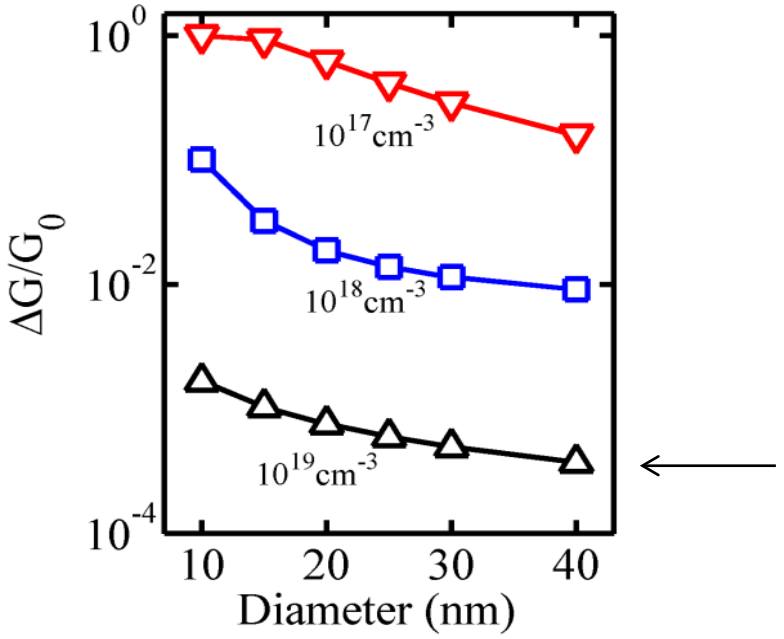




Sensitivity Gain: Geometry of Electrostatics ?

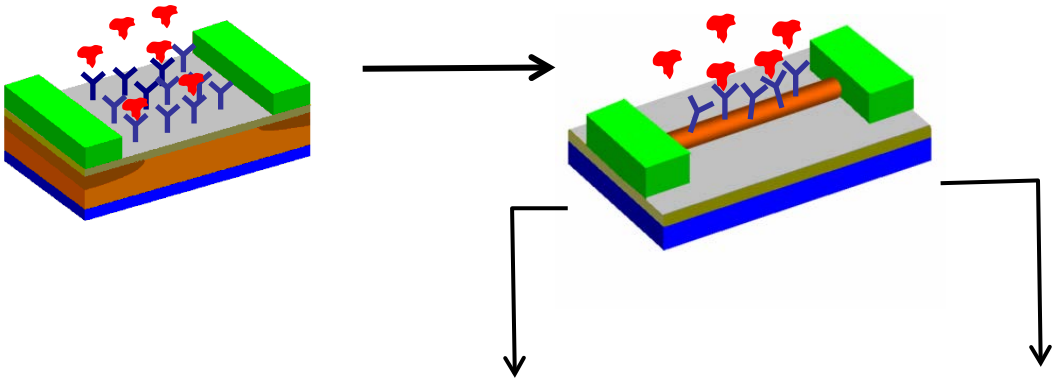


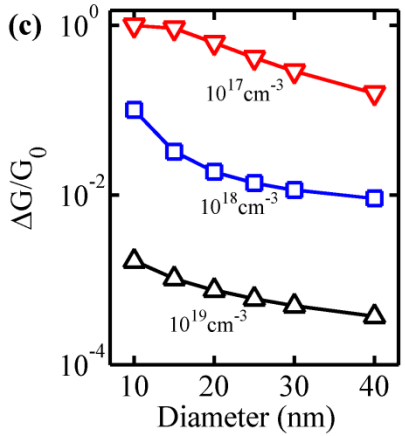
$$S = 2N_{bio}/RN_D$$



- Same result from experiments
- Simple surface-to-volume ratio does not explain the dramatic improvement

Geometry is Important, but exactly how ?





Berg, 1963

Geometry of electrostatics

Geometry of diffusion

Conclusions

- Potentiometric, amperometric, and cantilever-based sensors measures various aspects of the biomolecules (e.g. charge, mass, reactivity, affinity) to identify molecules.
- Neither the method of transduction, nor the geometry of electrostatics explain the dramatic response.
- There must be something else about the shape of a nanobiosensor that makes it so sensitive.