Flexible Platinum nanoparticle strain sensors

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Outline

- Interest for sensors fabricated at room-temperature
- Vacuum deposited nanoparticles
- Strain sensors on silicon and flexible substrates
- Conclusions

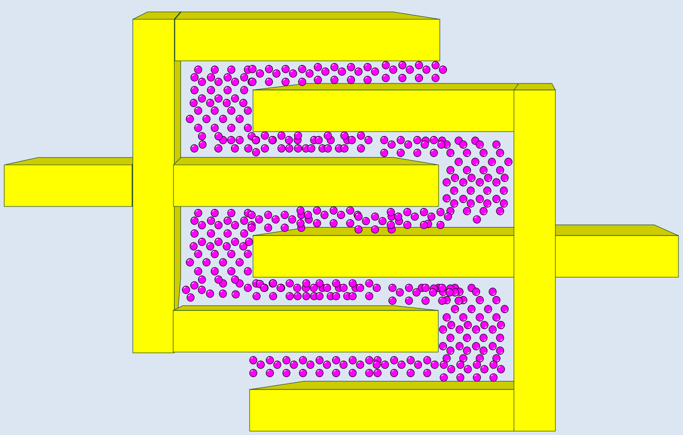
Motivation

•Co-integration of sensors with electronics requires sensor fabrication at low temperature

•If in addition the sensor can be demonstrated on a flexible substrate new application opportunities can emerge

•Metallic nanoparticles based sensors might present such opportunities

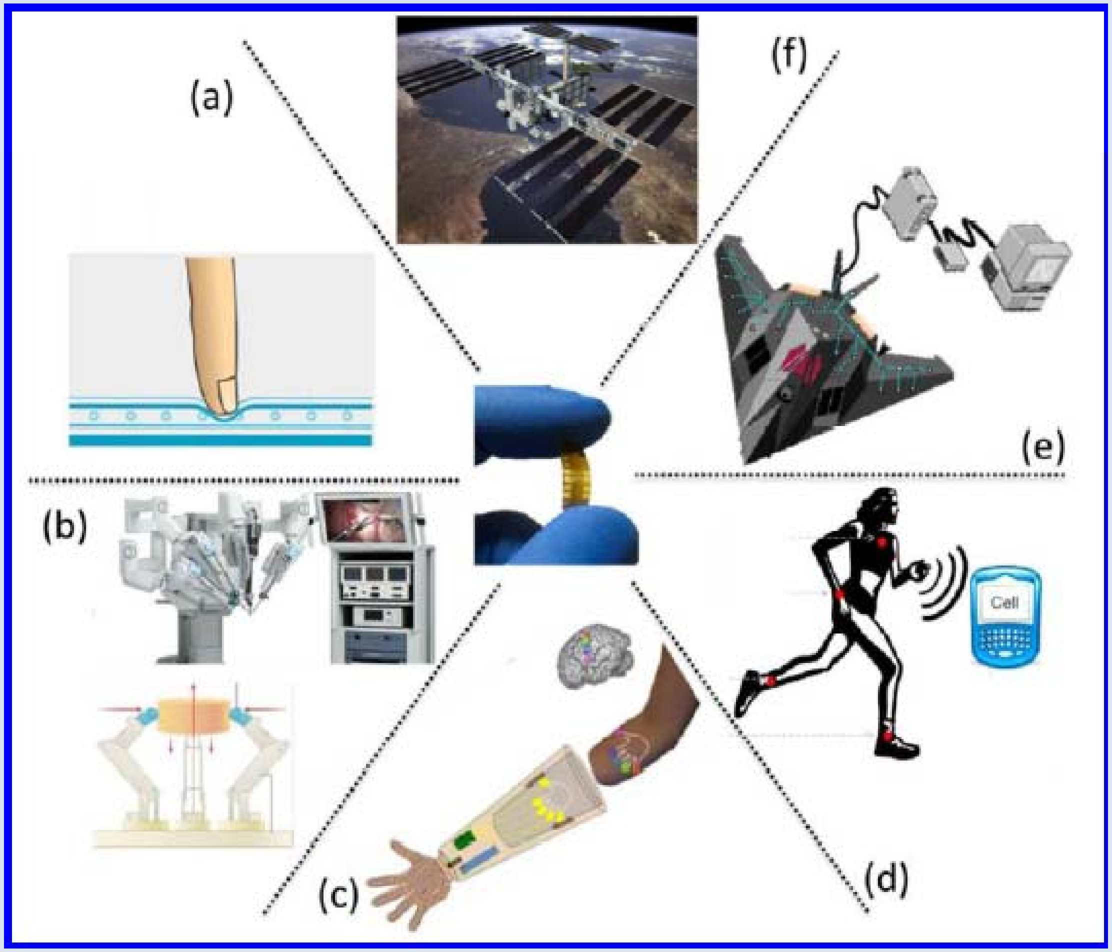
The sensor



•Nanoparticles form a conductive network between two interdigitated (IDE) electrodes

•The electrodes are formed by metal deposition and lithography

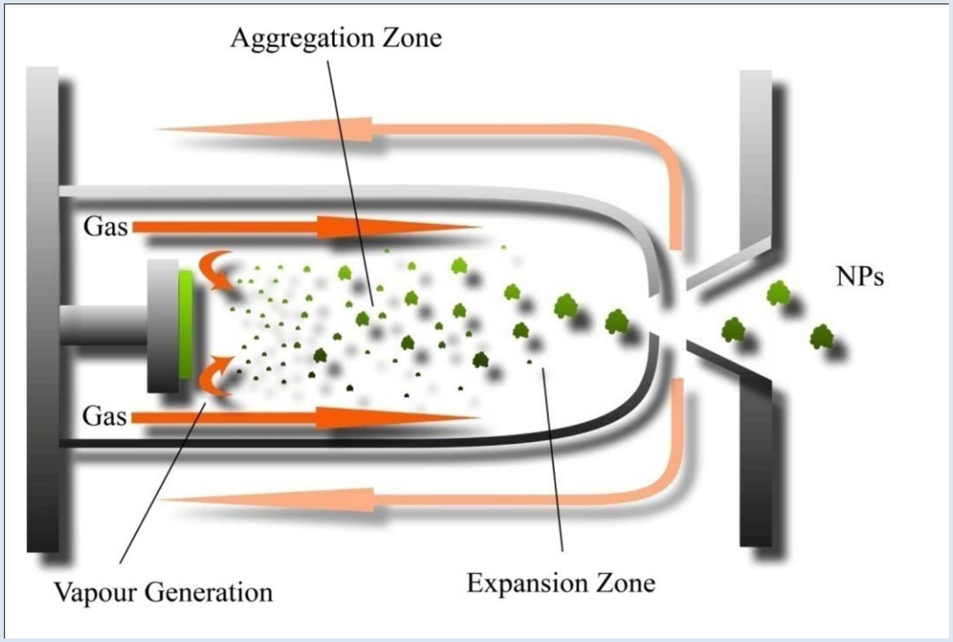
Applications



(a) Touch screen
(b) E-skin for robotics
(c) E-skin for prosthetic limbs
(d) Wearable sensors
(e) , (f) Space applications and structural health monitoring

Review Paper: M. Segev-Bar and H. Haick, ACS nano, Sept. 2013

Nanoparticle Source



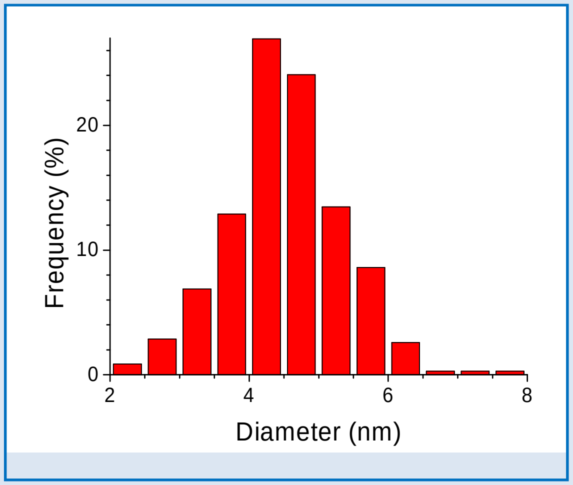
We have investigated electrostatic self-assembly of nanoparticles and Ostwald-ripening:

- Nanotechnology 20 365605 (2009)

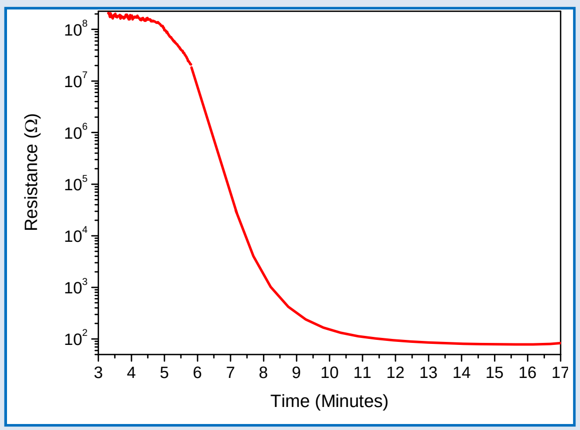
- Nanotechnology 22 235306 (2011)

- J. Materials Research, Special Issue on Self-Assembly (2011)

TEM images of Platinum nanoparticles with various substrate surface coverage



Size distribution

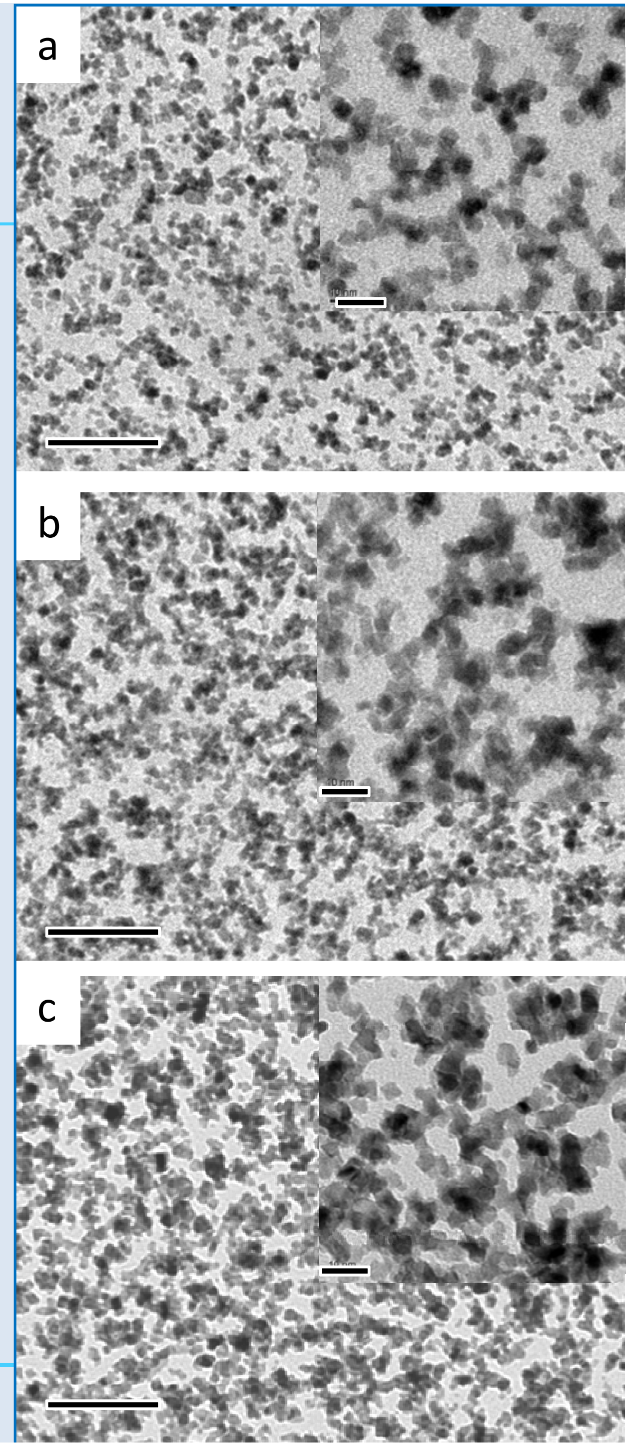


In situ measurement of Resistance

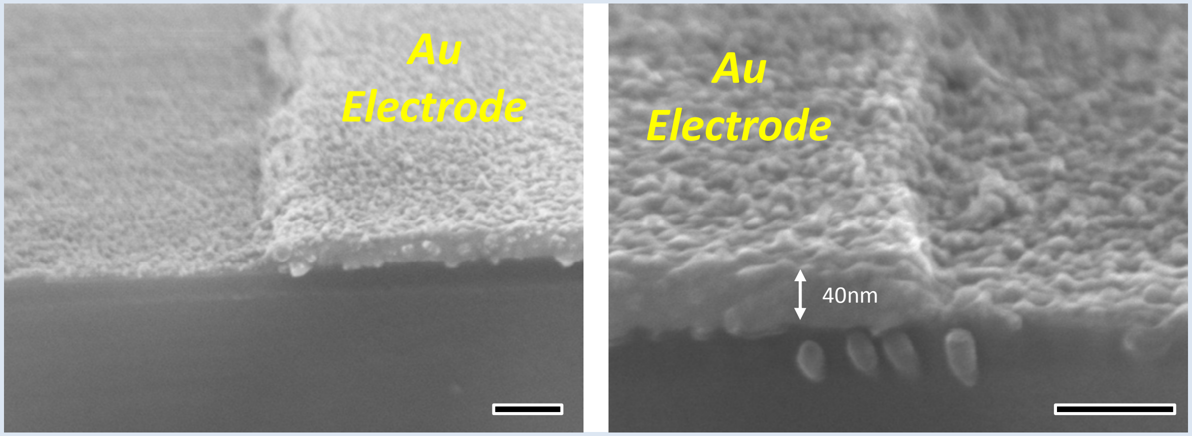
a) 36%

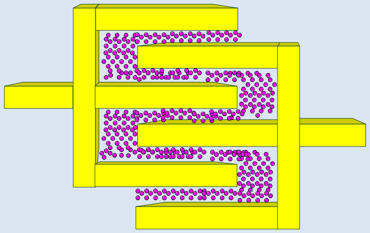
b) 42%

c) 48%



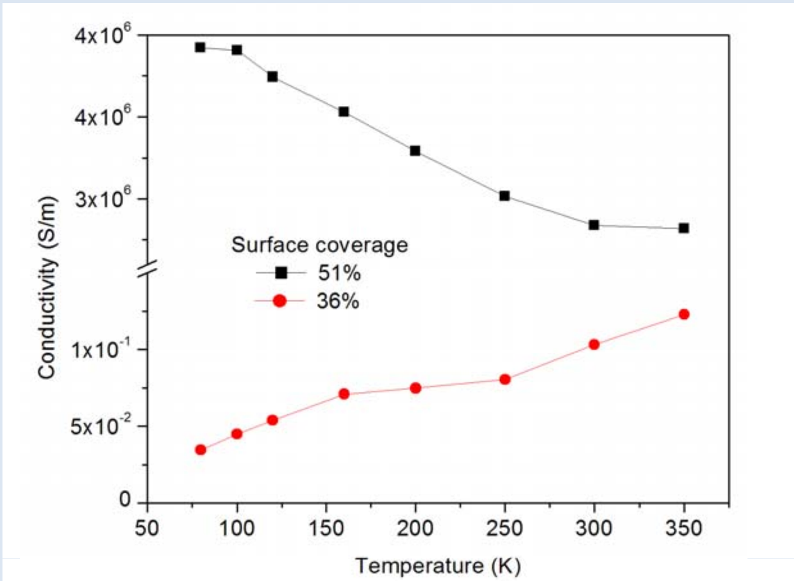
Electrode fabrication



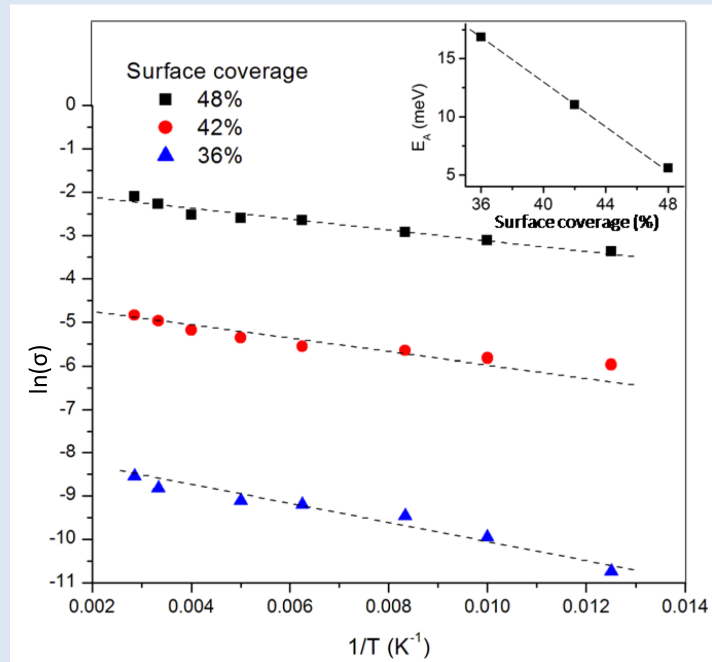


- Gold electrodes formed by e-gun evaporation and lift-off process
- Small electrode thickness needed to avoid shadowing effects during nanoparticle deposition
- Positive slope of electrode pads needed for their efficient electrical communication with nanoparticles

Electrical Resistance of nanoparticle assemblies



Conductivity vs. T



- When surface coverage exceeds ~ 50% a metallic behavior is observed

R ↑ T

Discussion

For nanoparticle assemblies conductivity can be approximated* by a thermally activated conduction :

$$\sigma \propto \exp(-2d\beta)\exp\left(-\frac{E_a}{RT}\right)$$

***d* ,** **is the core–core separation**

***β* ,** **is a quantum mechanical tunneling factor**

E_a , **is the activation energy for charge hopping**

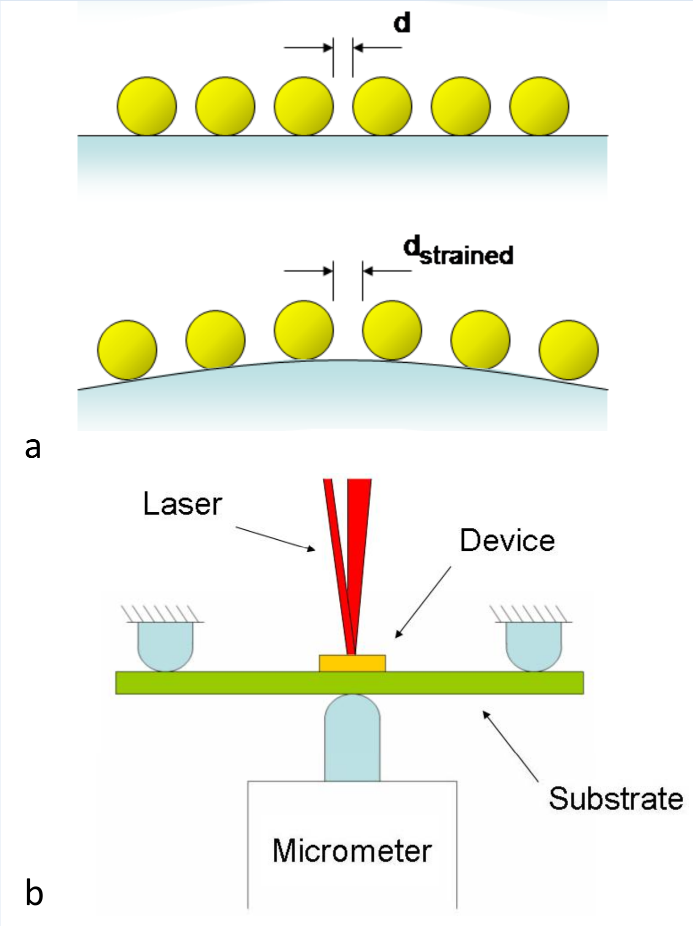
$$E_a = 0.5e^2 \frac{r^{-1} - (r+d)^{-1}}{4\pi\varepsilon_r\varepsilon_0}$$

r* , *radius of nanoparticle

This exponential dependence provides a sensitive detection mechanism for any parameter or process that changes the barrier width

S. Beloborodov, A. V. Lopatin, V. M. Vinokur and K. B. Efetov , Rev. of Modern Physics, April 2007

Demonstration of a strain sensor



$$g = \frac{\Delta R / R}{\varepsilon} = \frac{\Delta R / R}{\Delta L / L}$$

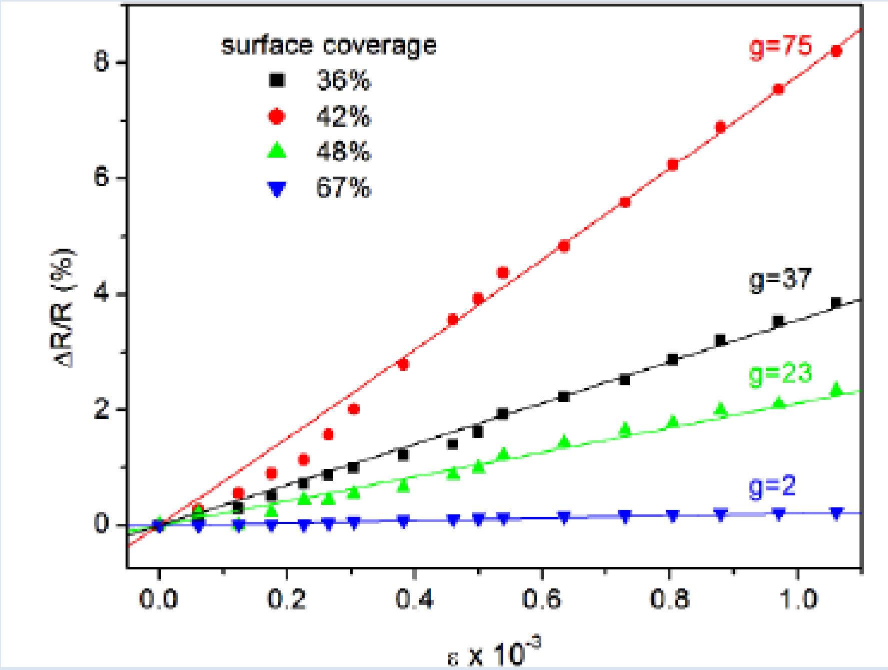
$$\varepsilon = \Delta l / l$$

Dramatic increase of gauge factor:
Values of g > 70 are obtained
(to compare with g ~ 2 - 4 for continuous Pt films)

$$\varepsilon = T_s / 2R_b$$

T_s: sample thickness
R_b: radius of curvature

Results



Relative resistance change as a function of strain of nanoparticle films for various np densities

It can be shown that neglecting the thermally activated term:

$$\Delta R/R = \exp(g\varepsilon) - 1 \qquad (1)$$

for εg << 1 (1) simplifies to:

$$\Delta R/R = \varepsilon g \qquad (2)$$

Equation (2) is used to draw the lines in figure and estimate gauge factor

Influence of nanoparticle density on strain sensitivity

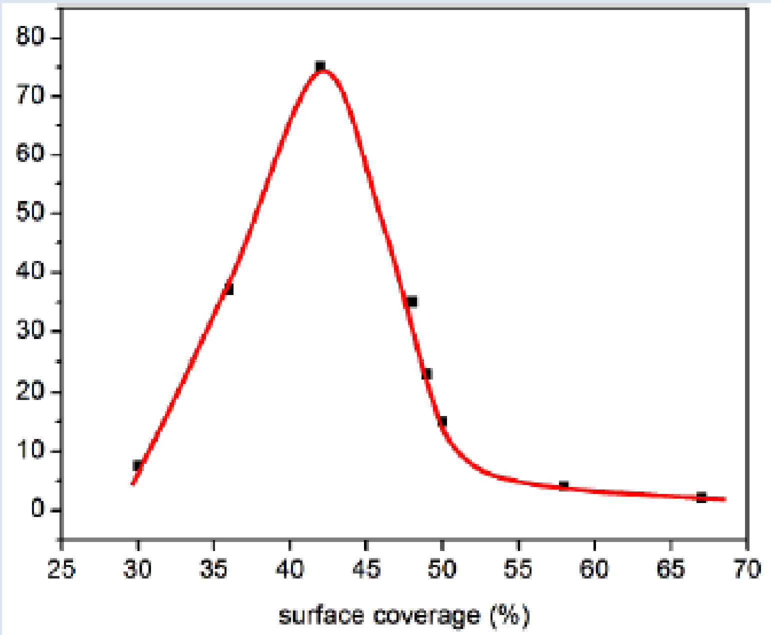


Figure: Gauge factor as a function of surface coverage (experimental results)

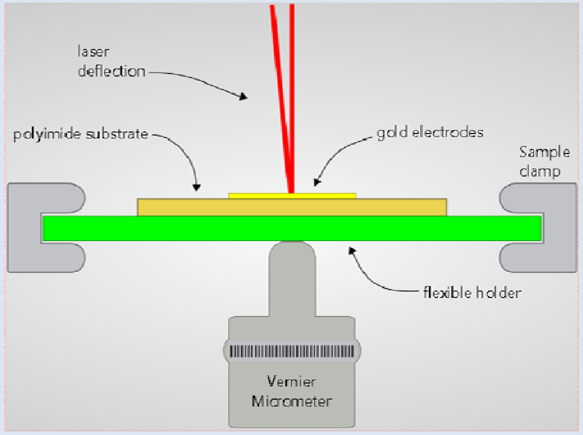
Using equation below that does not neglect the thermally activated term we can qualitatively obtain figure results

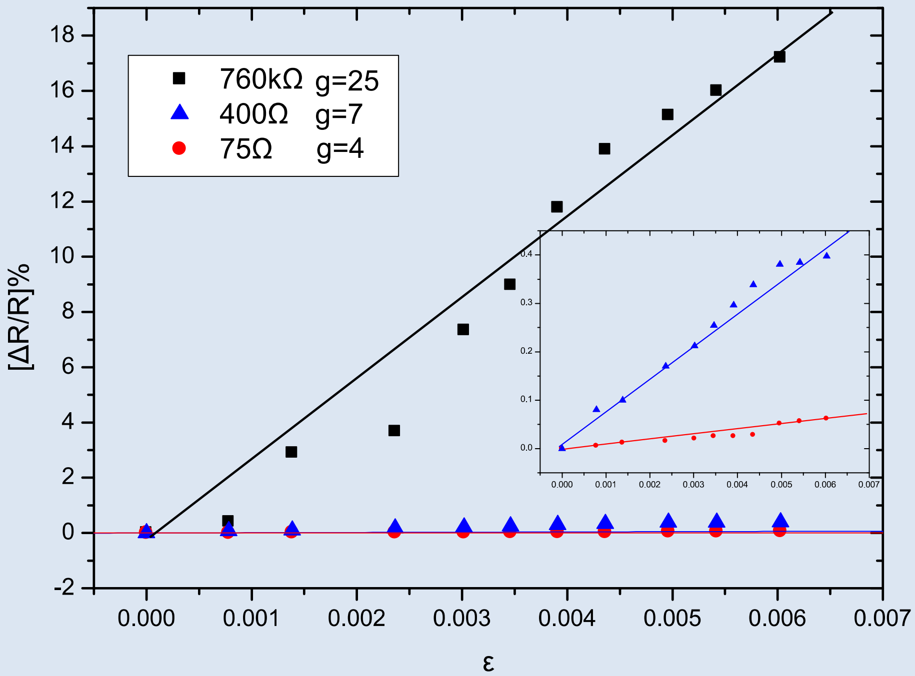
$$\frac{\Delta R}{R} = \exp\left[(2r+d)\times\beta\varepsilon\right]\exp\left[7.14\times\left(\frac{1}{r+d}-\frac{1}{(r+d)+(2r+d)\times\varepsilon}\right)\right]-1$$

http://nanotechweb.org/cws/article/lab/50231

Nanotechnology 23 285501 (2012)

Strain Sensor on Polyimide substrate



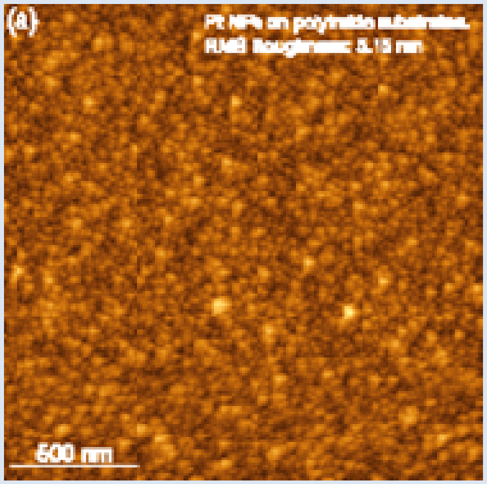


High resistance sample: Gauge Factor estimated at 25

Substrate: Kapton HN, 75 um thickness

Surface roughness by AFM

SiO2/Si



5,15 nm RMS roughness

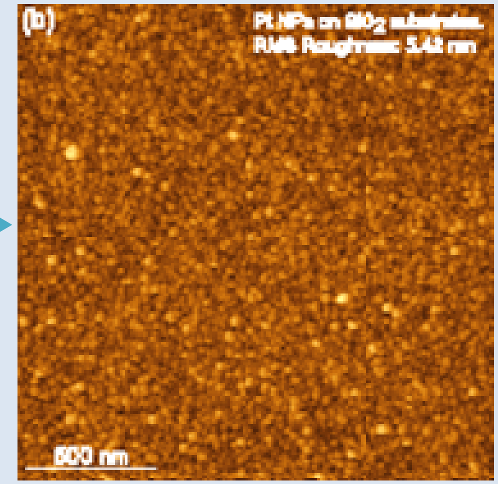
AFM images following Pt nanoparticle deposition on :

SiO2/Si →

← **polyimide**

Similar roughness values obtained

Poyimide



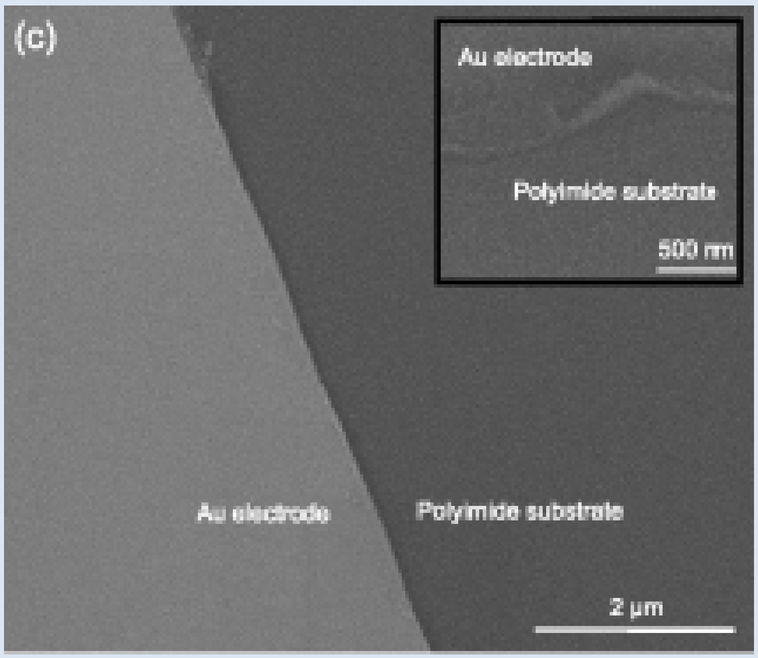
5,42 nm RMS roughness

Before nps Deposition

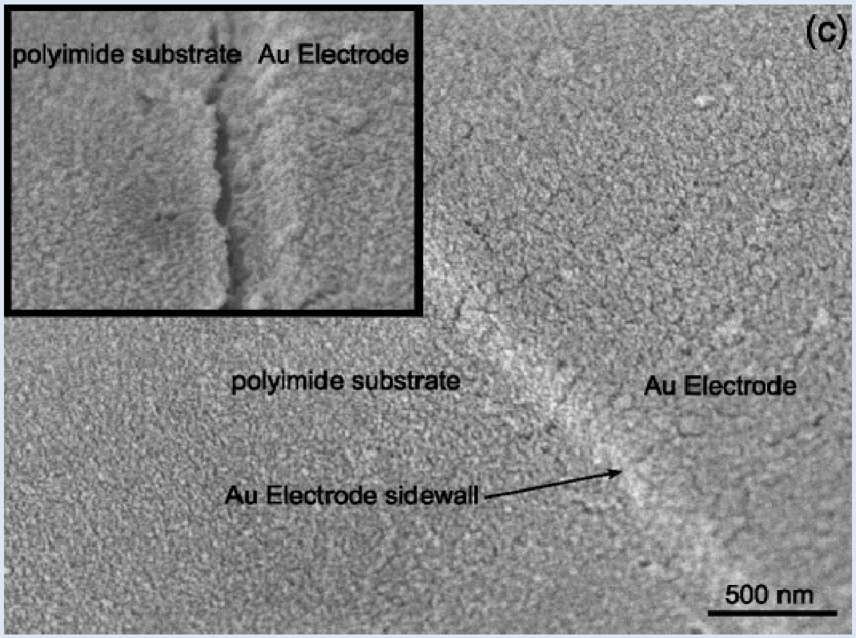
0, 4 nm RMS roughness

0,6 nm RMS roughness

SEM Images of metallic electrodes on PI



SEM general view of electrode



SEM image showing the existence of cracks on polyimide

Conclusions

- We have investigated room temperature Physical Deposition technique to deposit metallic nanoparticles.

- Either metallic or thermally activated behavior was observed for charge transport in nanoparticle assemblies depending on their density

- By controlling the np density we can optimize the design of sensors through ‘inter-particle space engineering’

- Strain sensors demonstrated on silicon and flexible substrates through this concept

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THANK YOU FOR YOUR ATTENTION !