

Dual Beam approach to fabrication of sub-20nm gap nanoelectrodes

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Outline

- Motivation: Nanoelectronics
- Techniques available with a FIB-SEM workstation
- Method 1. Tilted e-beam Pt deposition: sub-10 nm gap
 - Structural and compositional analysis,
 - mechanical stability
- Method 2. Planar e-beam Pt deposition: sub-10 nm gap
- Method 3. FIB cutting: sub-20 nm gap electrodes
- Conclusions

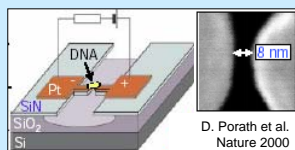


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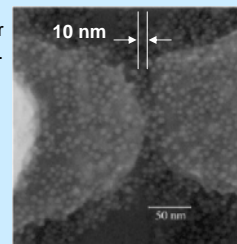
The motivation: Nanoelectronics

- Probe transport properties at the molecular size (molecular-electronics and single-electron devices)
- Nanostructures matching the molecular size (< 10 nm)



- Electrical transport through single DNA molecules.

- Single Electron Transistor using CdSe nanocrystals.



D.L. Klein et al., Nature 1997

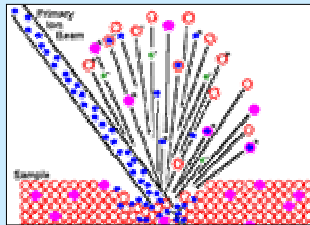
- All the fabrication methods (Break-junction, electrochemical deposition, shadow-mask deposition) involve the many steps of conventional lithography (optical, EBL) before nanogap fabrication.



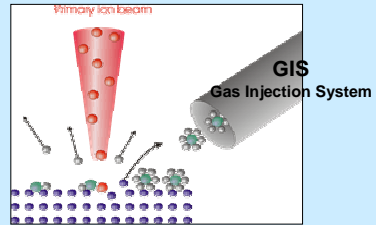
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Dual Beam approach to nanogap fabrication

FIB milling



Beam-induced deposition (electrons)



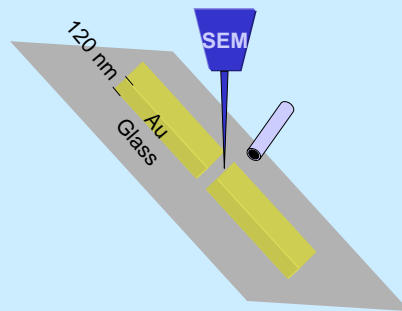
- Fully in-situ, one-step approach, on the bare sample.
- Nanoscale control of electrodes placement
- Flexibility in shape and geometry of the structures (deposition)



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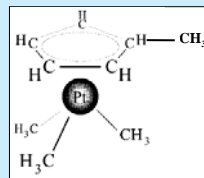
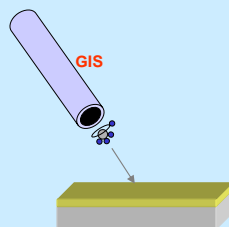
Method 1: tilted e-beam deposition

Dual Beam FEI Strata DB 235M



Fabrication Steps

- 1) Au removal by FIB milling leaving 0.5 μm gap Au pads
- 2) Bridge the Au wires by tilted (45°) e-beam deposition of pillar electrodes



$(\text{CH}_3\text{C}_5\text{H}_4)(\text{CH}_3)_3\text{Pt}$
(methylcyclopentadienyl-trimethyl-Pt)

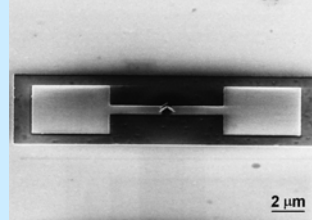


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Step 1 and Step 2

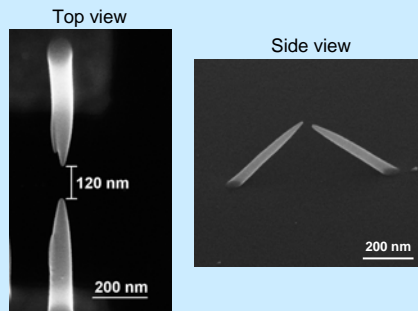
STEP 1: FIB milling

- $5 \times 5 \mu\text{m}^2$ Au pads with $3 \times 1 \mu\text{m}^2$ arms separated by a $0.5 \mu\text{m}$ gap.



STEP 2: Tilted e-beam depo 100 nm Ø pattern, 90 s

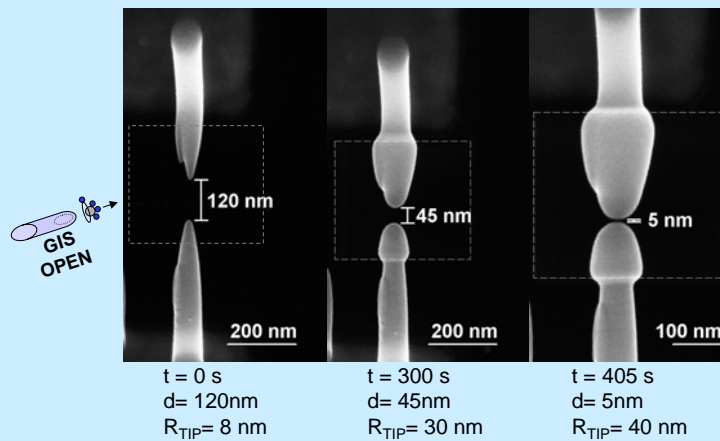
- Large gap electrodes: $d=120\text{nm}$
- $L=600\text{nm}$, $\varnothing=90\text{nm}$, $R_{\text{TIP}}=8\text{nm}$
- Branch on the left = stage drift



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Step 3: Visually-controlled gap size

- SEM scanning over the tips ($400 \times 350 \text{ nm}^2$) under gas flow



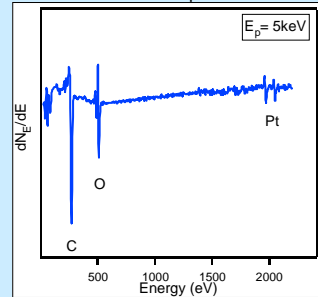
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Characterization

- Compositional analysis: **Auger**

C	51 at.% ($\pm 20\%$)
O	14 at.%
Pt	35 at.%

e-beam Pt deposition

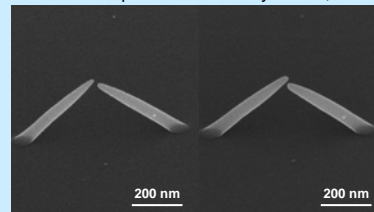


- Electrical properties: ...under way, ($\rho \sim 0.01 - 0.05 \Omega \text{ cm}$, [Edinger, JVSTB 2001])

- Mechanical stability, a trivial test:

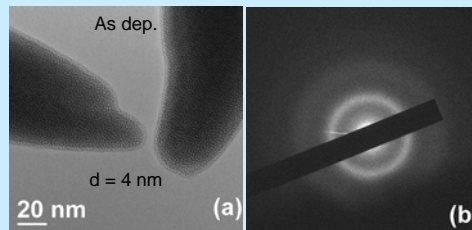
Stable at RT, in air.

As dep. 3 days in air, RT



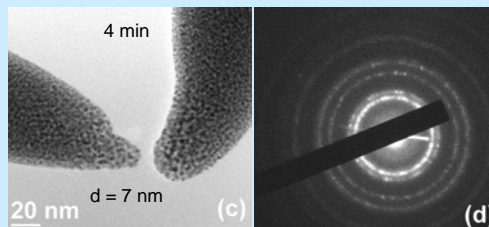
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TEM analysis



- Pillars as deposited: Pt grains embedded in amorphous carbon matrix

- High current ($J \sim 100 \text{ A/cm}^2$) TEM irradiation: annealing effect ? **Yes !**



4 min. irradiation

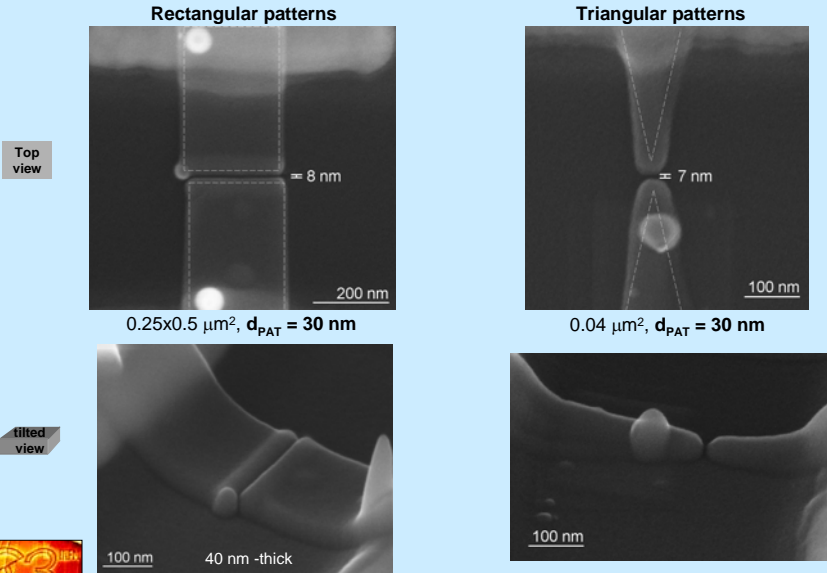
- Pt grains increase in size: diffraction rings are clearly resolved.
- Surface roughness increases
- The structures are stable: only small changes in shape and gap size



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Method 2: planar e-beam deposition

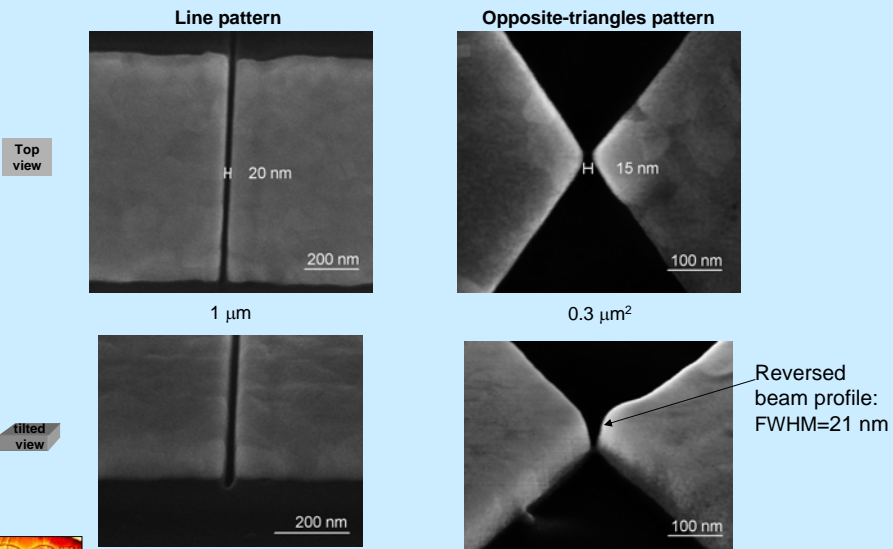
- Electrodes are deposited within the FIB patterned gap using two pattern shape



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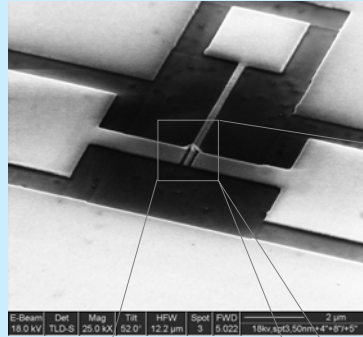
Method 3: FIB direct lithography

- The Au contacts are cut using the smaller beam size (1 pA, 7 nm)

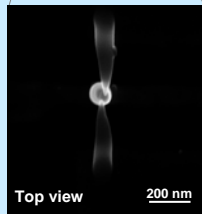
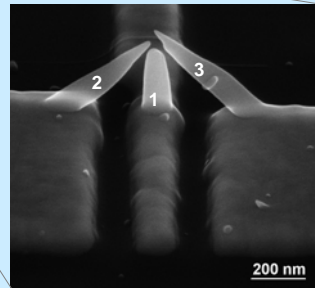


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Flexibility of DB fabrication: multi-electrodes structures



- Triode structure
- Deposition sequence: pillar 1, 2 and 3



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Conclusions

- ❑ Tilted e-beam deposition allows fine control of gap size below 10nm, down to SEM resolution: **5 nm gap fabricated.**
- ❑ Tilted pillar-electrodes are mechanically stable. Local annealing increases crystallinity and size of Pt grains (35 at%) embedded in a C (51%) and O (14%) matrix.
- ❑ Planar e-beam deposition offers less control but similar resolutions were achieved: **7 - 8 nm gaps.**
- ❑ FIB direct lithography is less resolved but it is faster and cleaner: **15 – 20 nm gaps.**
- ❑ Dual Beam (FIB/SEM) fabrication offers high flexibility: **multi-electrodes structures**



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