Nanogap fabrication based on strained III-V beams

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Nanogap fabrication based on strained III-V beams

Outline of the talk

- Introduction.

- Examples of Nanogap fabrication methods.

- Description of our new strategy : strained single - crystal beams.

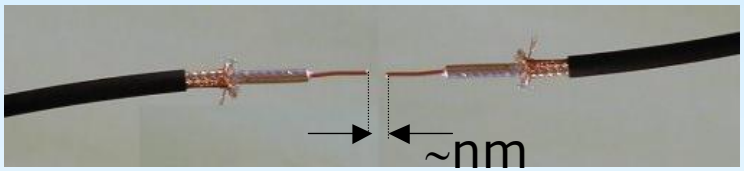
- Summary.

Introduction

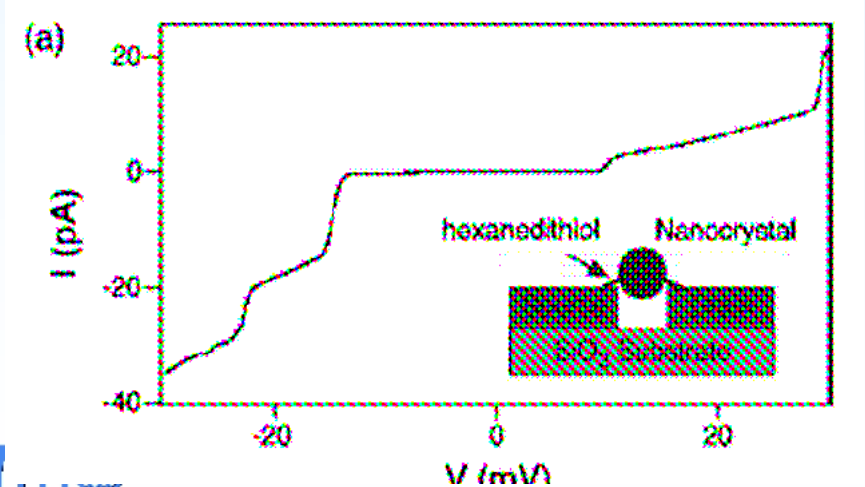
Nanogap definition:

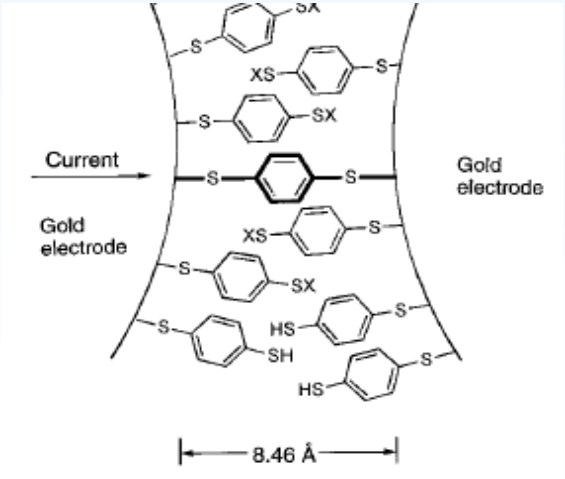
'Separation between two contacts in the nanometer range'.

Interesting for :



Molecular Electronics: In particular for transport measurements in Single Molecule Junctions or nanoparticles.



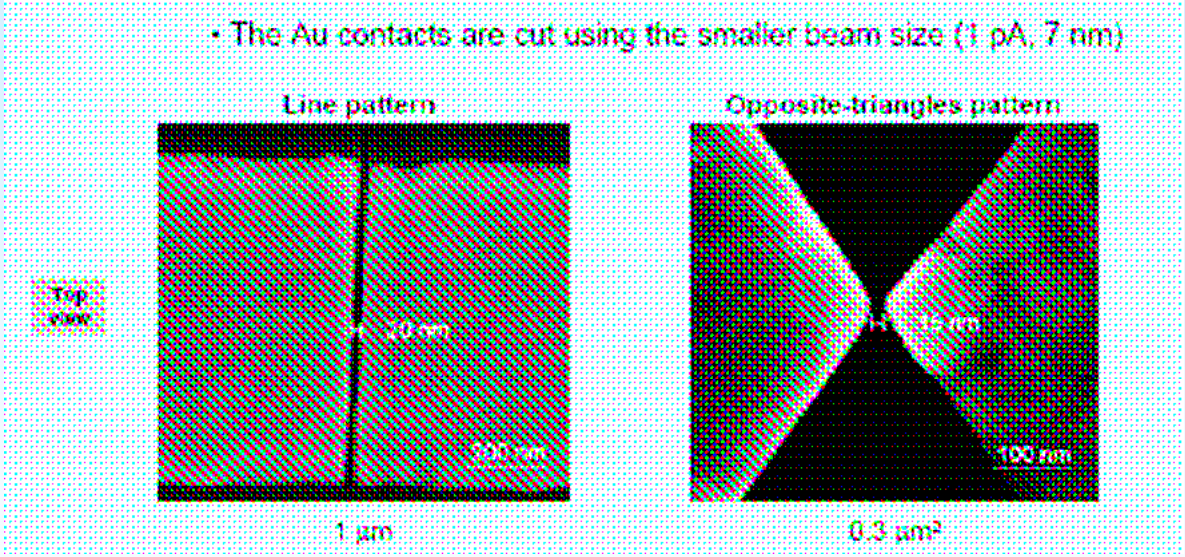


CSIC

Introduction

Problems:

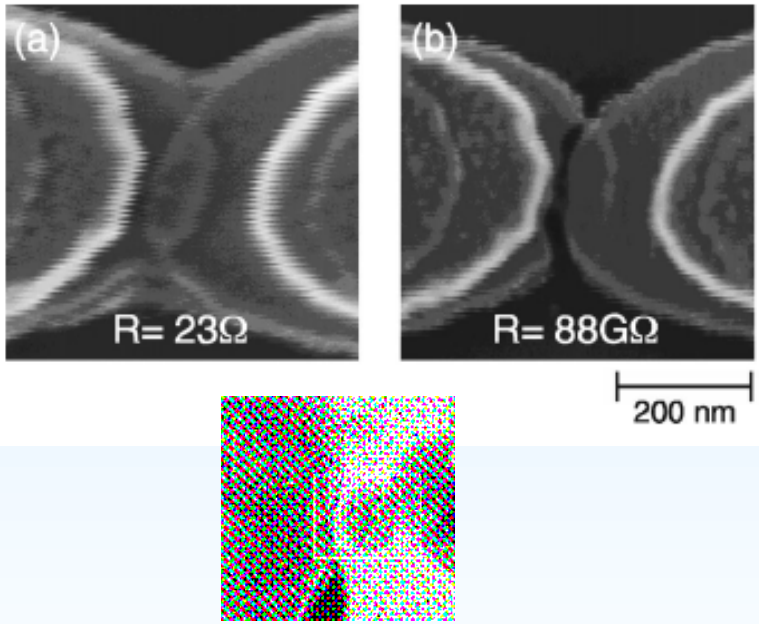
Limited resolution the standard micro-fabrication process (EBL, FIB...) ~15-20nm.



It is neccesary to explore alternative fabrication methods.

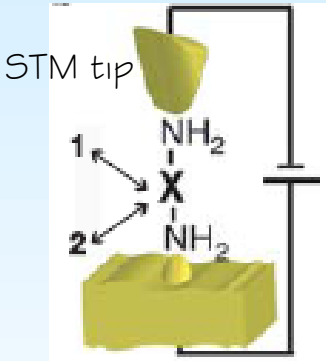
Fabrication methods : Examples

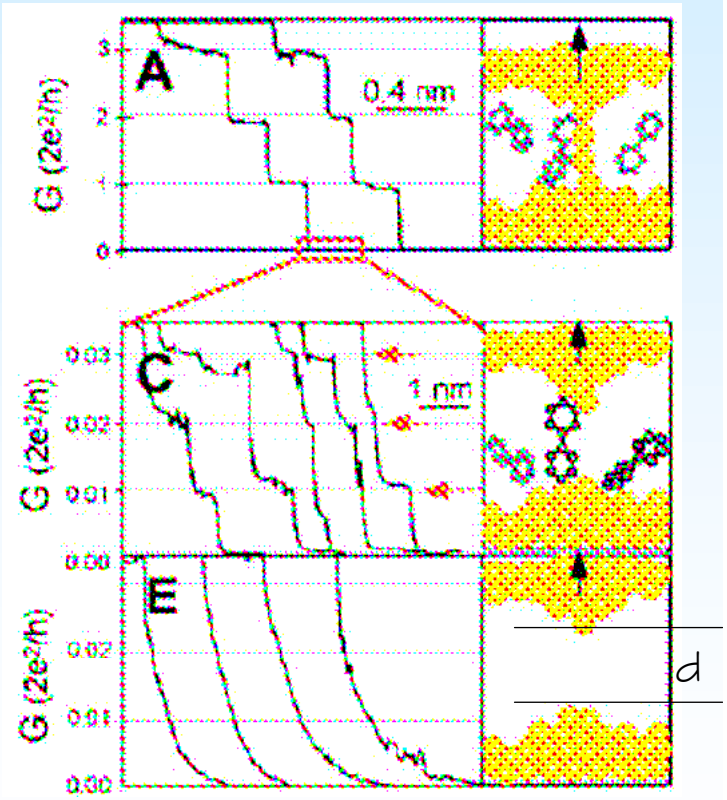
Electromigration
(breaking metallic wires passing through a current $10^7 A/cm^{-2}$)



P. Alivisatos, APL, **75**, 730 (1999)
D. E. Johnston, Nanoletters, **7**, 2774 (2007)

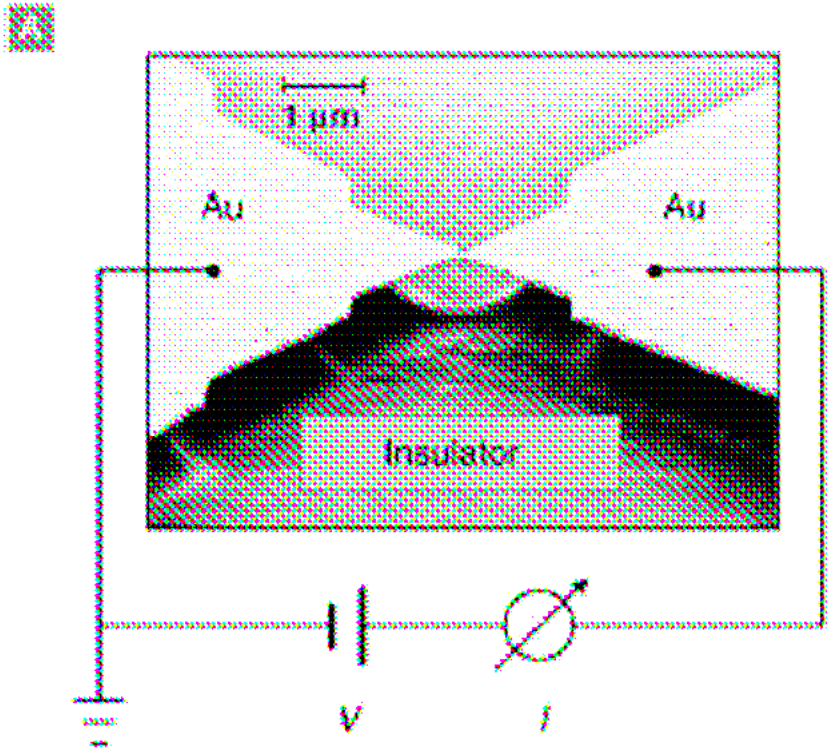
SPM techniques
(precise control of the tip-surface distance) Single atom conduction

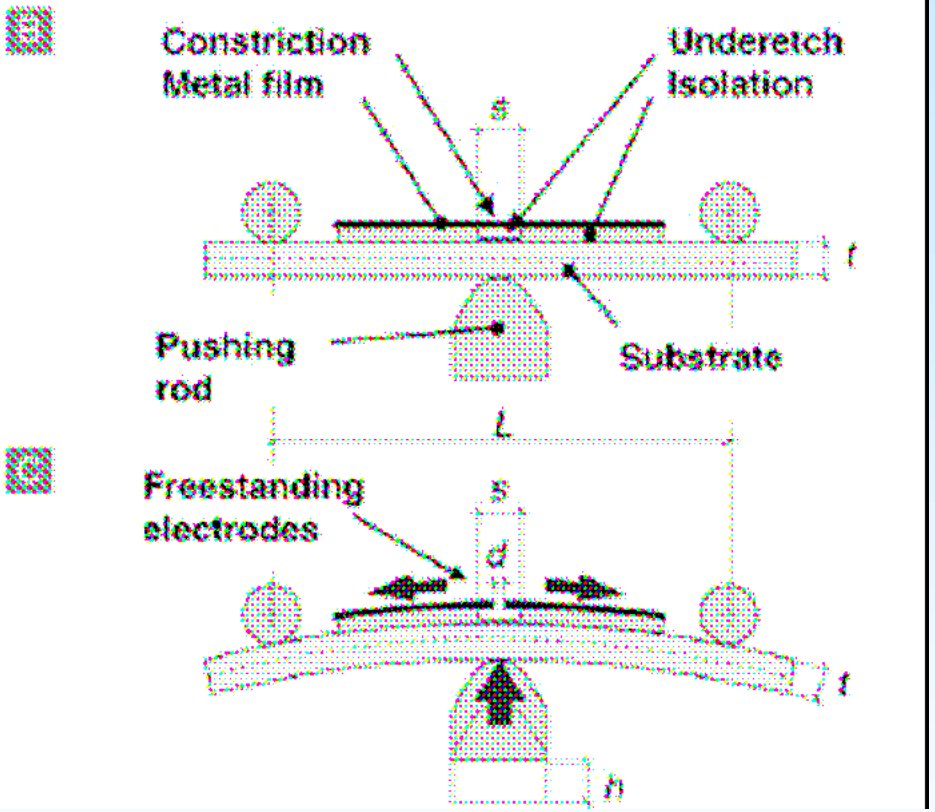




J.L.Costa-Krämer, PRB, **55**, 4875 (1997)
L.Venkataraman, Nature, **442**, 904 (2006)

Fabrication methods: Mechanically Controlable Break Junction.





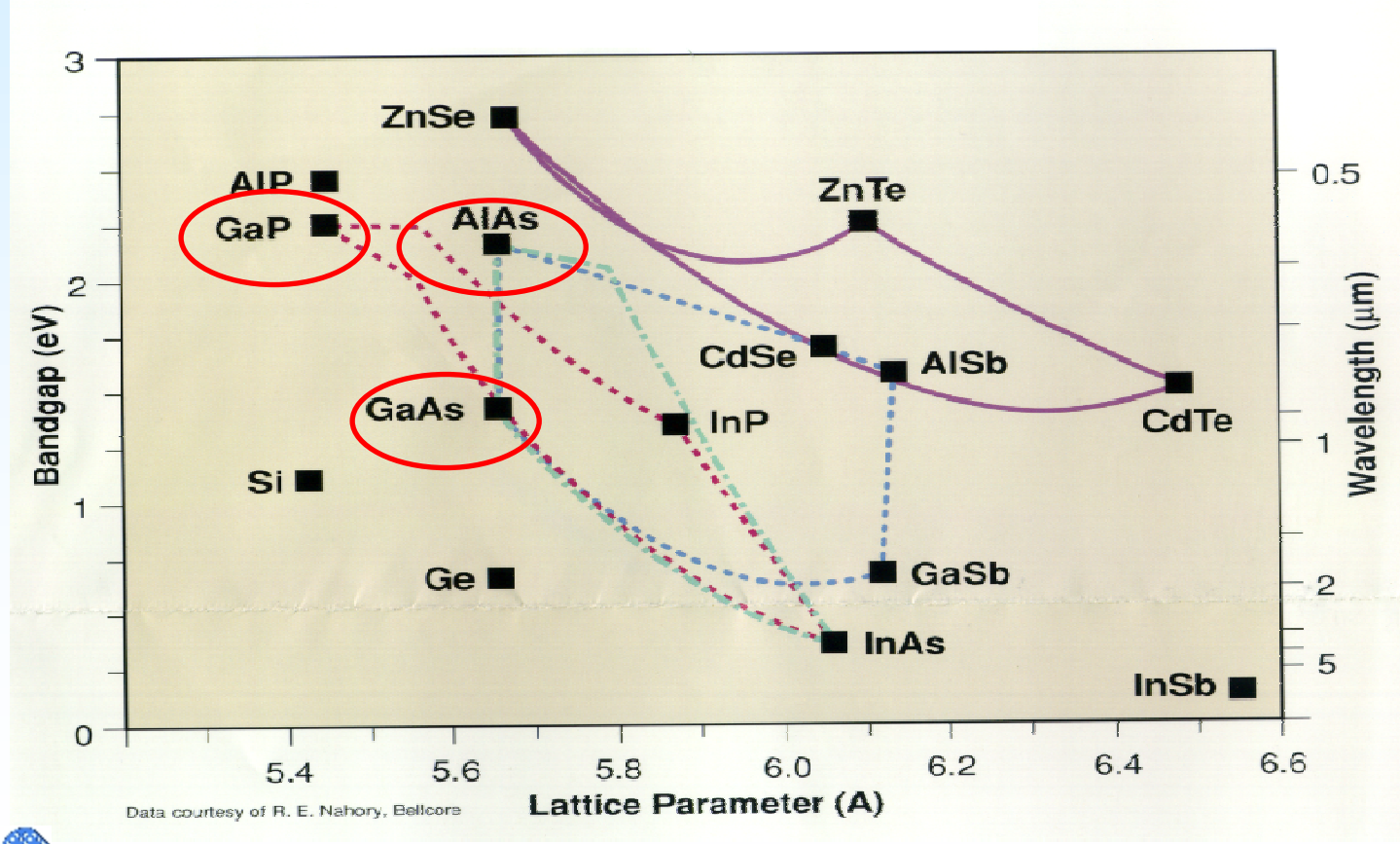
Broken microbridge

E. Lörtscher et al., Small, **2**, 973 (2006)
A. R. Champagne et al., Nanoletters 5 305 (2005)

III-V single crystal **strained** epitaxial heterostructures

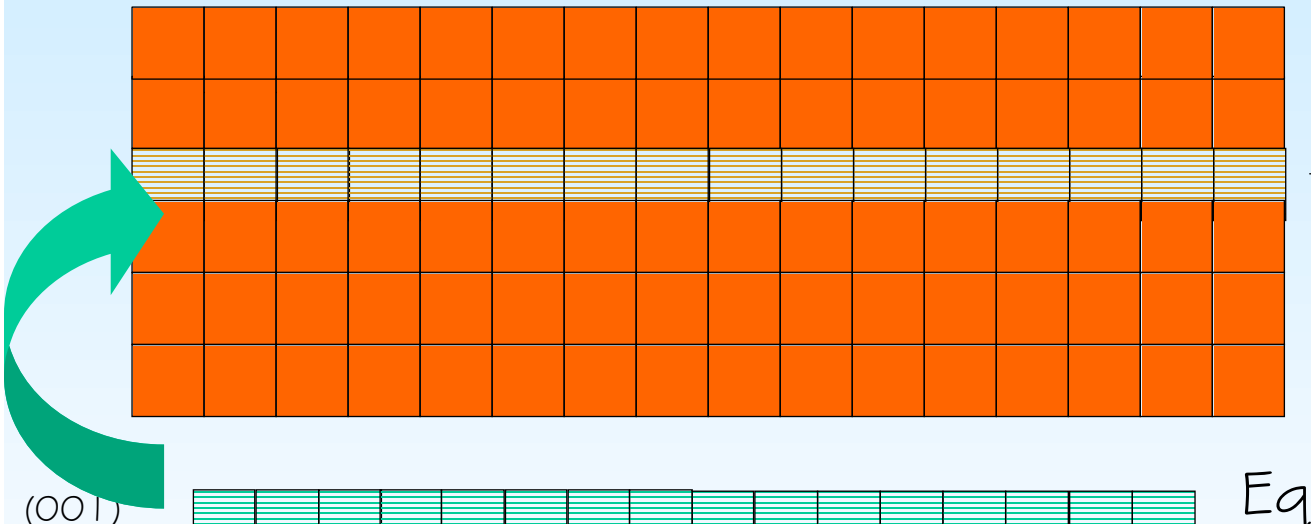
Single crystal heterostructures containing GaAs, AlGaAs and GaP.

Ability of ALMBE to grow heterostructures with large lattice mismatch GaAs and GaP ($\Delta a = 3.6\%$) with atomic precision.



GaP on GaAs: mismatch accomodated by strain

Single GaP ML between GaAs

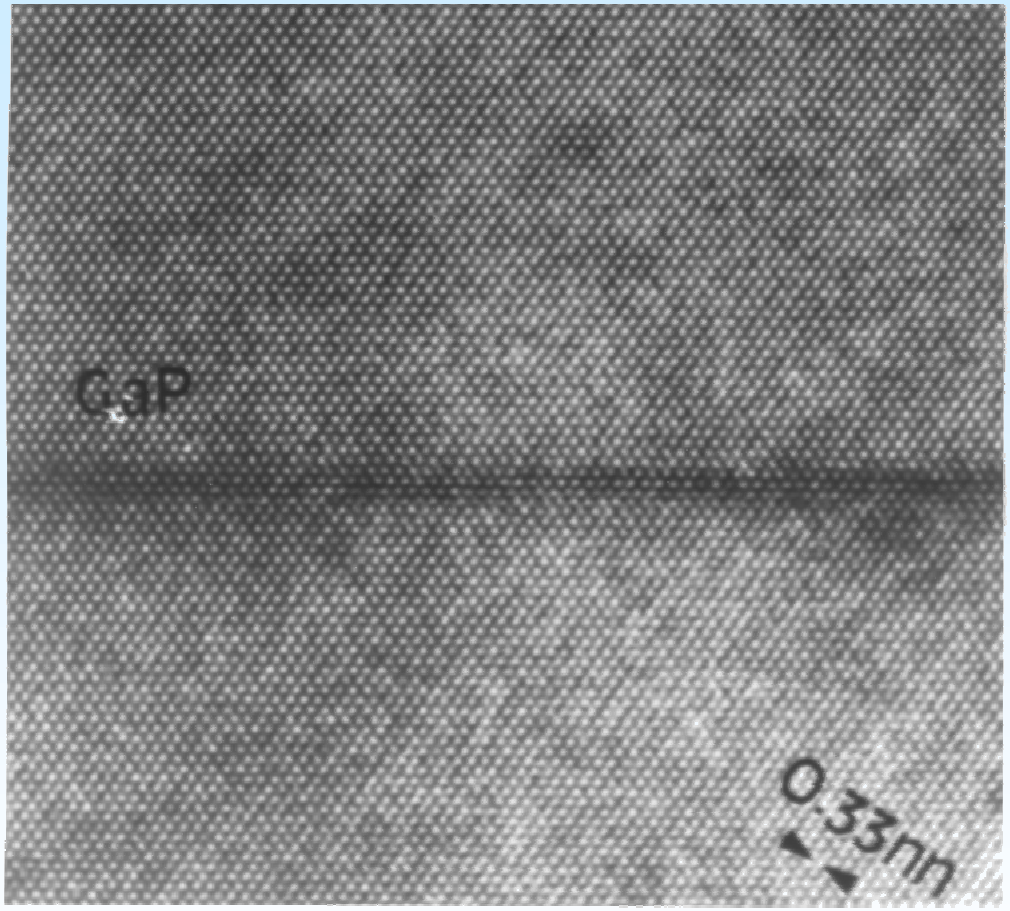


Equilibrium GaP
(a=5.45 Å)

Lattice mismatch (Δa)

- Accomodated by strain
- Accumulates an in-plane tensile stress (σ) $\sigma = M_{biaxial}\ \Delta a$

2 GaP ML embedded on GaAs: mismatch accomodated by strain



← GaAs

→ Strained GaP

← GaAs

Capability for obtaining flat and abrupt interfaces

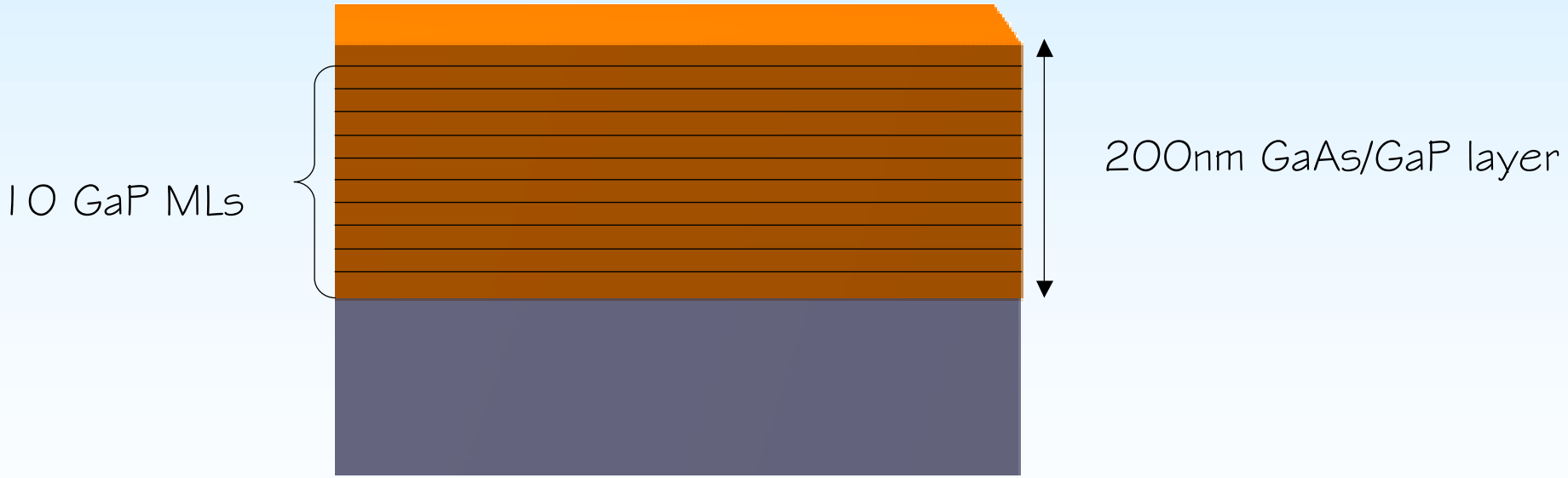
F. Briones et al., Appl. Phys. A **49** 729 (1989).

A Mazuelas et al. J. Phys. D **26** A167 (1993).

Grown layer by ALMBE: GaAs/GaP

10 single GaP ML's symmetrically distributed in 200nm thick layer.

Each GaP layer is separated by 64 GaAs ML's (no misfit dislocation)

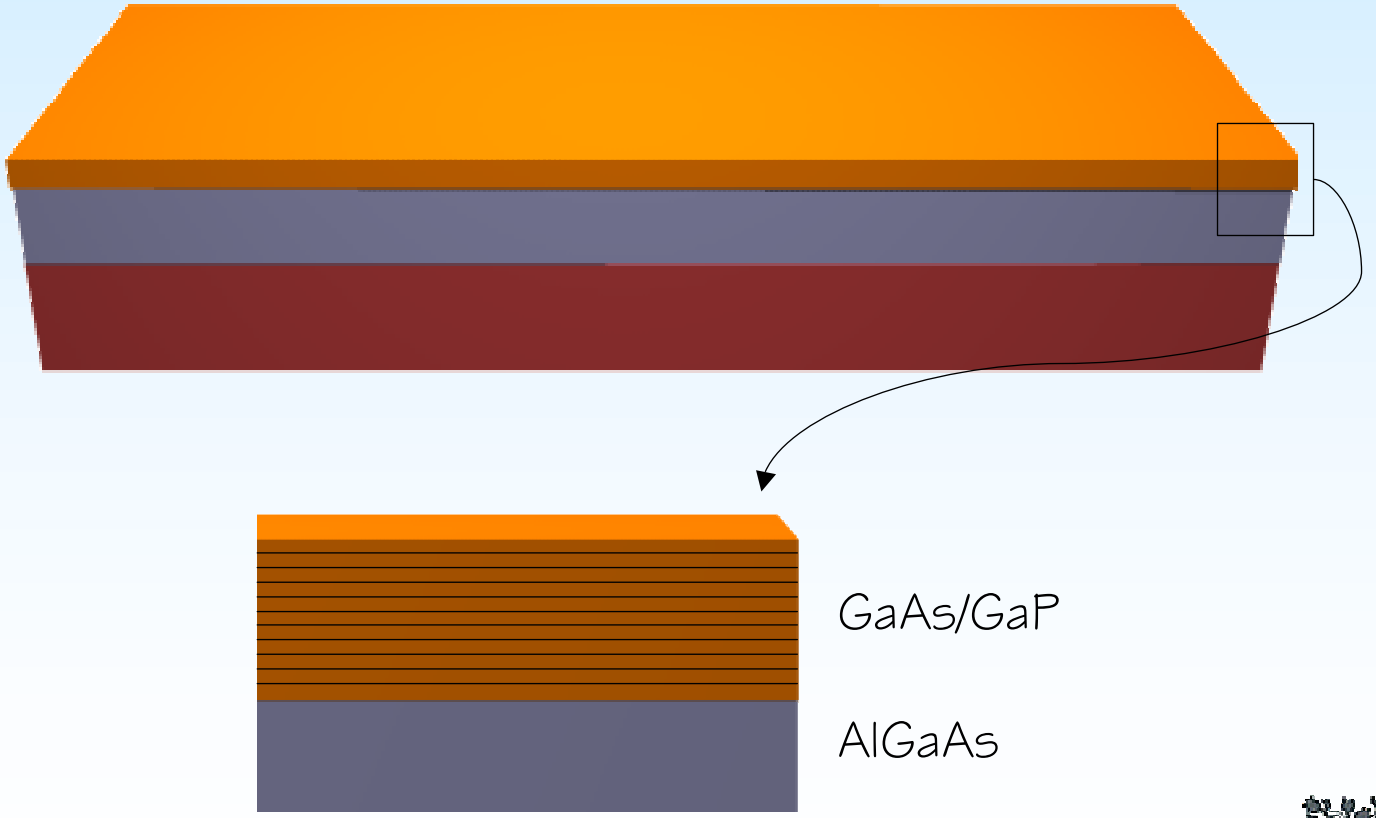


GaP 'stressors' of atomic thickness are introduced

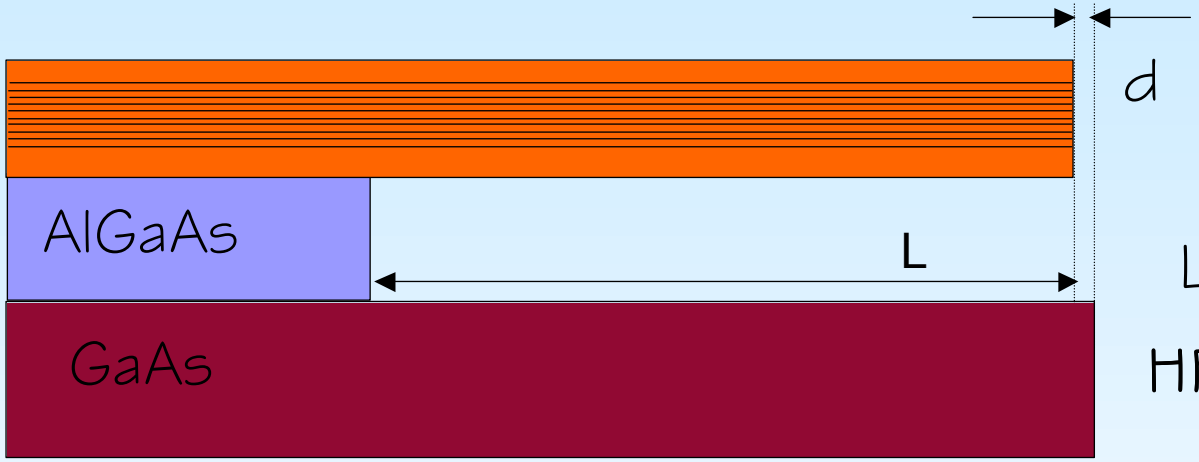
ALMBE grown GaAs/GaP/AlGaAs/GaAs heterostructure

1 μm thick AlGaAs layer that acts as sacrificial layer.
HF Etching Selectivity AlGaAs/GaAs = 10^7:1 for microfabrication of structures

GaAs/GaP (200nm)
AlGaAs (1 μm)
GaAs substrate



Strain release during AlGaAs layer etching



Contraction length

L=etched length

HF selective etching

Contraction length can be calculated by strain sharing model between GaP and GaAs layers.

$$d = \frac{L}{a} \cdot \varepsilon_{GaAs} = L \cdot \frac{\Delta a}{a} \cdot \frac{1}{1 + \frac{n_{GaAs}}{n_{GaP}} \cdot \frac{M_{GaAs}}{M_{GaP}}}$$

M=biaxial moduli

n=number of MLs

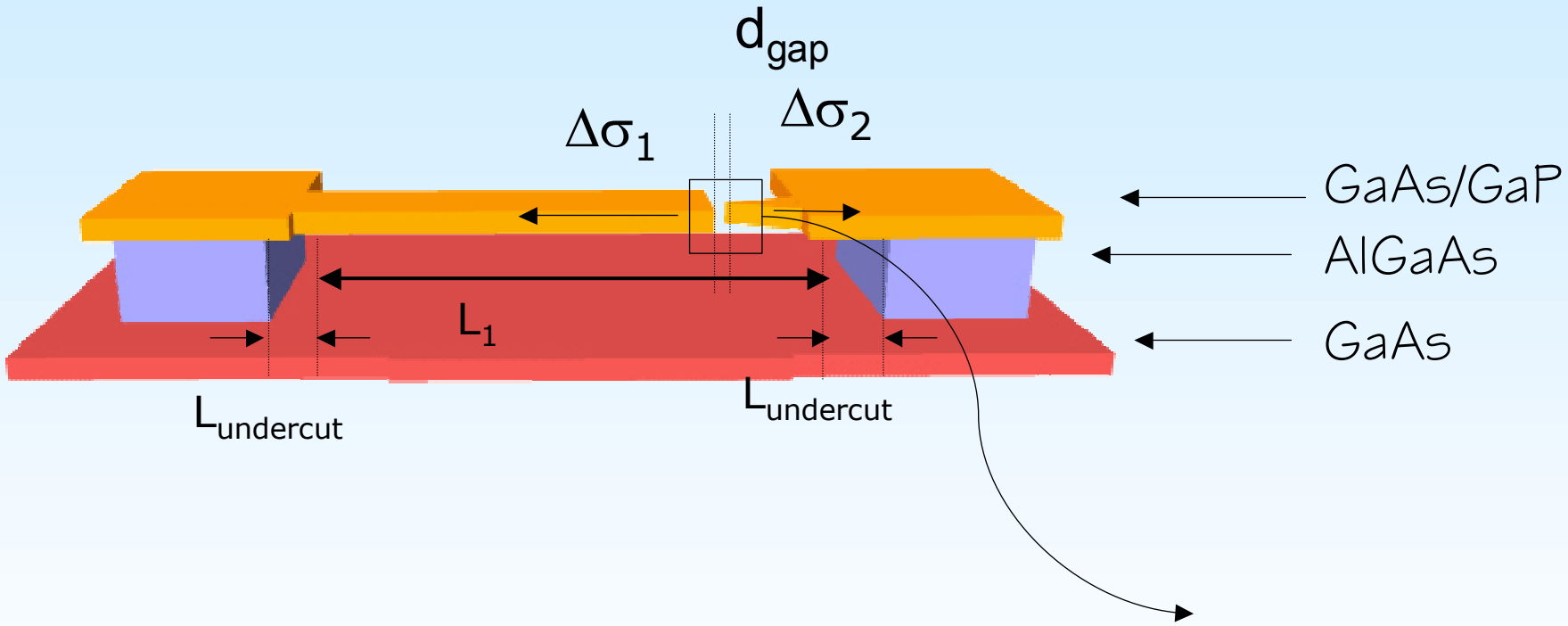
$$\frac{n_{GaAs}}{n_{GaP}} = 70$$

$$\frac{\Delta a}{a} = 3.6\%$$

L=10 μm → d=5nm

Strain-release-cleavage

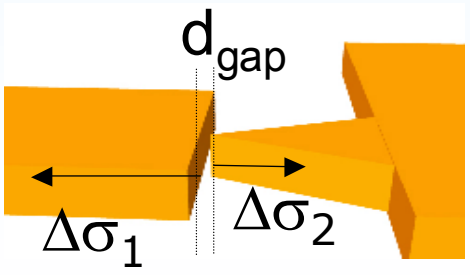
Nanoconstriction breaks by cleavage of GaAs/GaP strained layer during AlGaAs etching.Atomically flat cleavage planes.



Experimental Breakage conditions

Nanoconstriction of width t=300nm

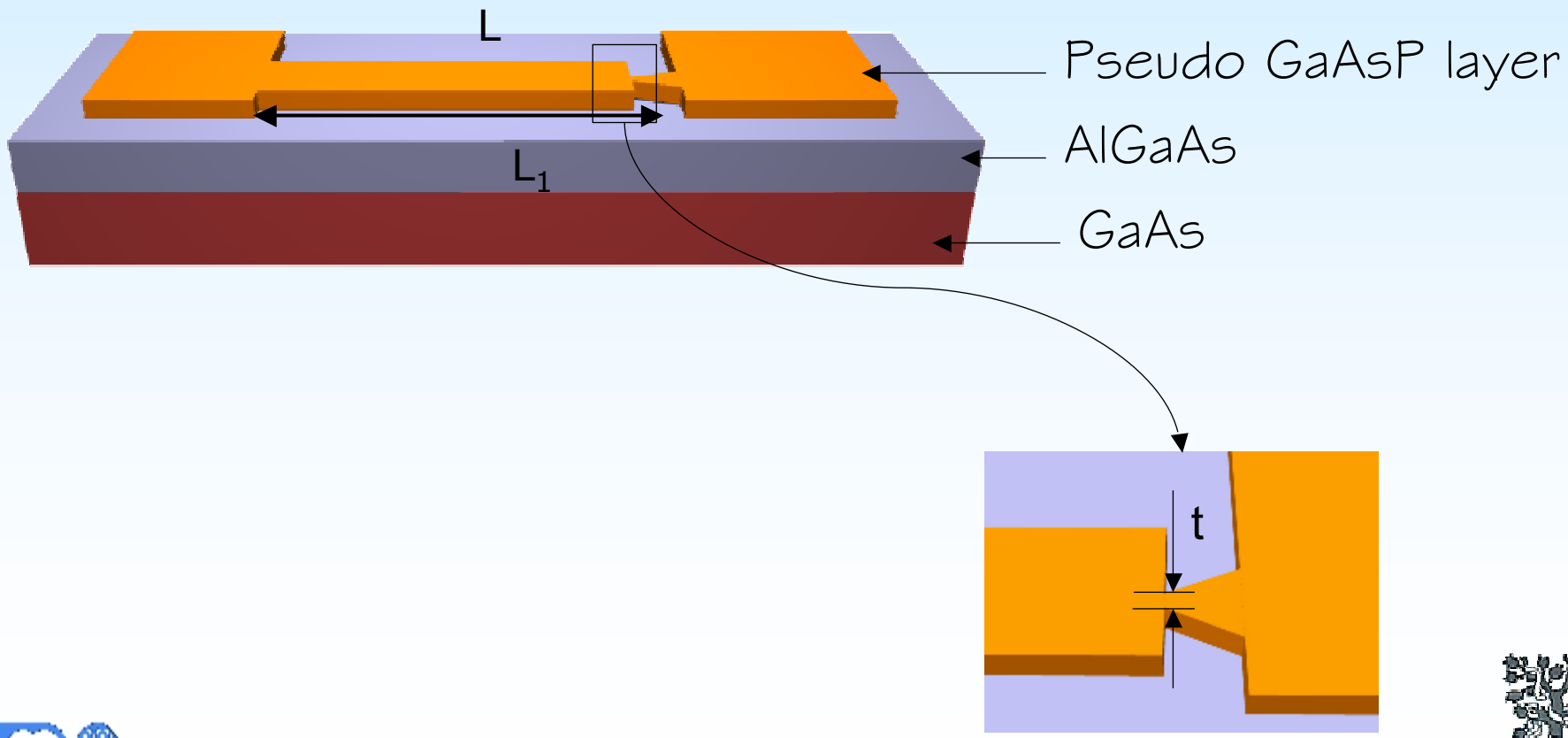
Beam length > 3.5 μm



How to turn this contraction into a nanogap?

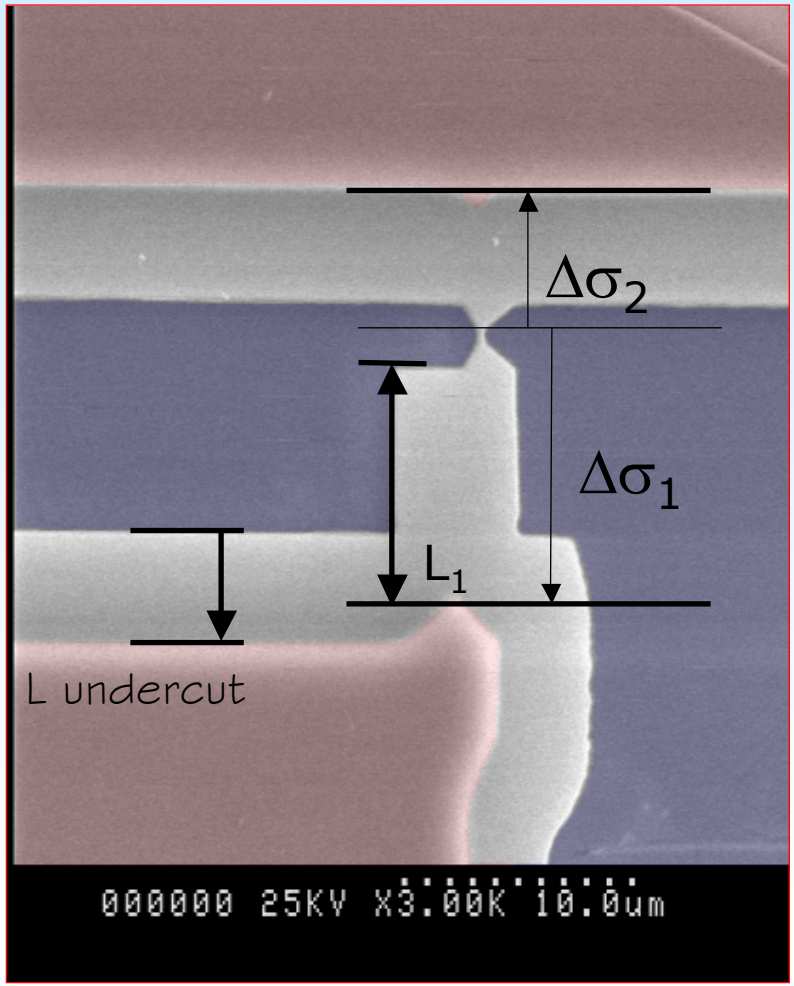
EXPERIMENTAL:

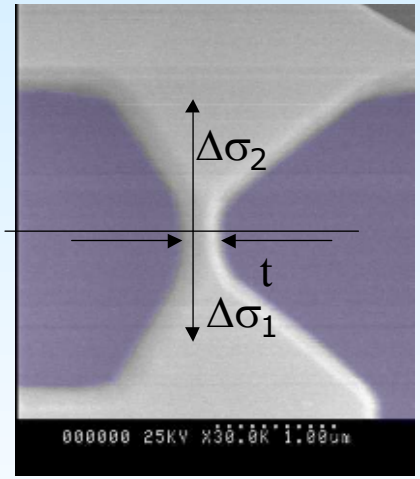
Beams with a narrow neck (nanoconstriction) are fabricated by EBL + wet etching of the GaAs/GaP layer.



Fabricated device

Top view

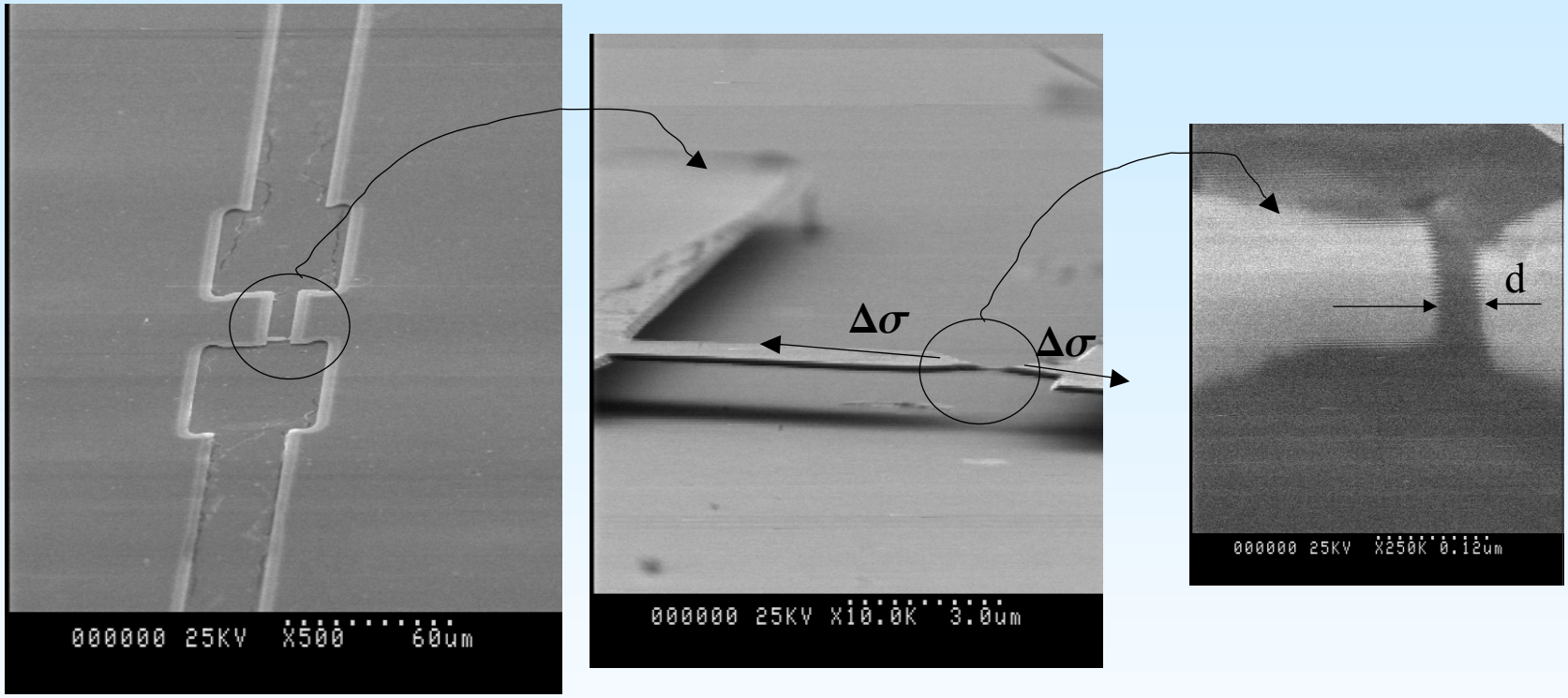




Colored SEM image of the etched device.

Fabricated device

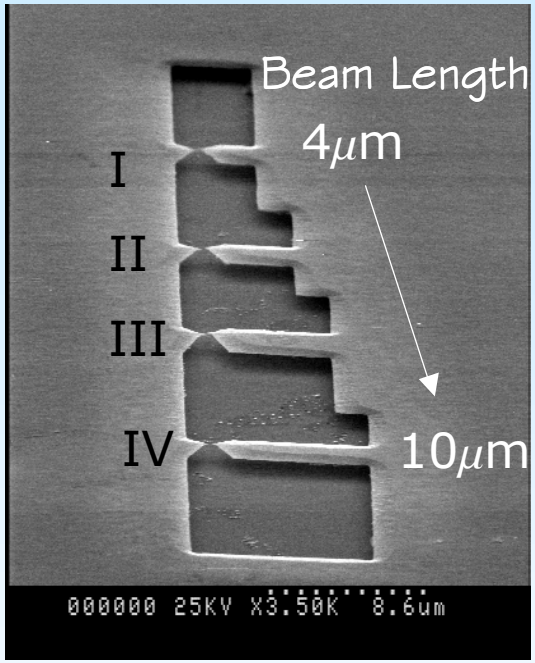
Side view

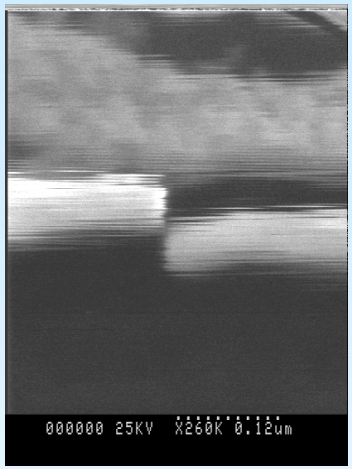


SEM tilted image of the etched device.

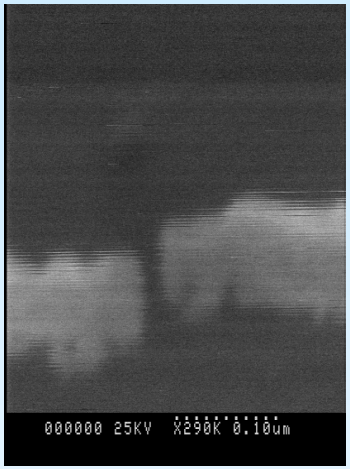
Two atomically flat surfaces separated a few nanometers.

Multiple nanogap fabrication: as small as 5nm!

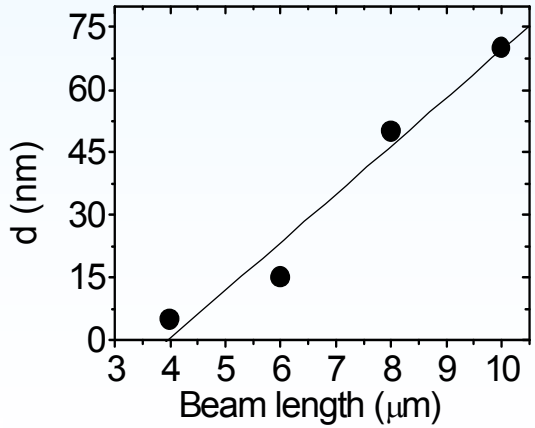




I:*d* ~ 5nm



II:*d* ~15nm



III:*d* ~ 50nm

IV:*d* ~ 70nm

Parallel nanogap fabrication using III-V epitaxial strained beams

Summary:

- A novel parallel nanogap fabrication method using strained beams is developed.

- The process is highly reproducible and allows precise gap size control. Full-wafer compatible technology

- Cantilever can be electrostatically actuated.

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Acknowledgments

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