EPFL

# MICRO-435 Quantum and Nanocomputing

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MT FABRICATION - PART 3

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4-5/11/23

# Molecular Transistor Fabrication

## Objectives

a) MCBJ

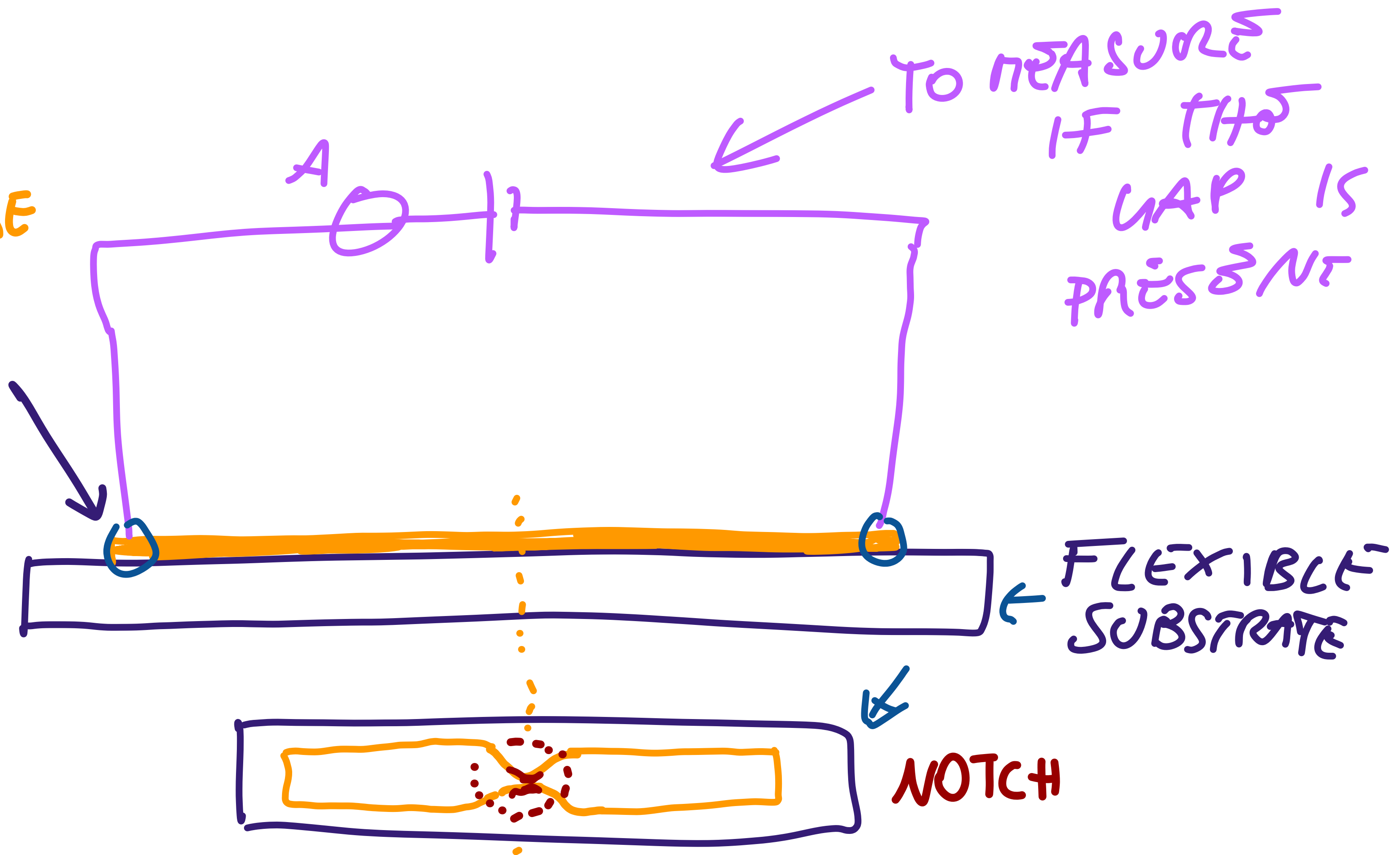
b) CDBJ

c) STAL

# GENERATION OF GAPS BASED ON MECHANICAL STRESS

## (a) MCBJ MECHANICALLY CONTROLLED BREAK JUNTION

GOLD WIRE DUCTILE AND HAS GOOD AFFINITY WITH ANCHORING



QUALITY VERY GOOD

DIFFICULTO FOR // GENERATION

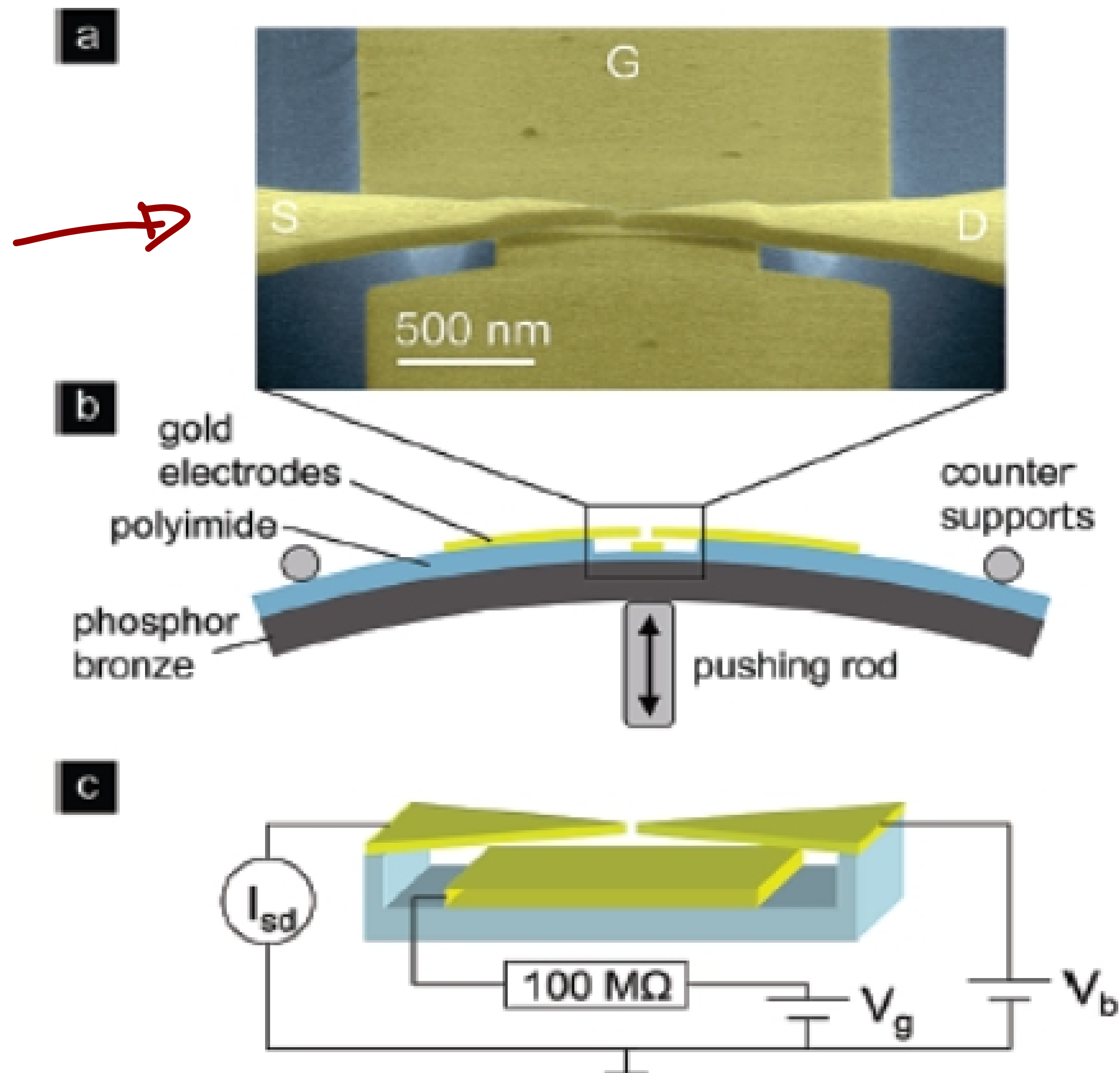
GOLD STRETCHED UNTIL RUPTURED

COUNTER SUPPORT

$\partial x$

PUSHING ROD

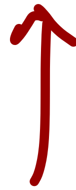
BENDING FINELY CONTROLLED




Christian A. Martin, Roel H. M. Smit, Jan M. van Ruitenbeek, *Nano Letters* **2009** *9* (8), 2940-2945
DOI: 10.1021/nl901355y

(b) CDBJ

CRACK DEFINED BREAK JUNCTIONS

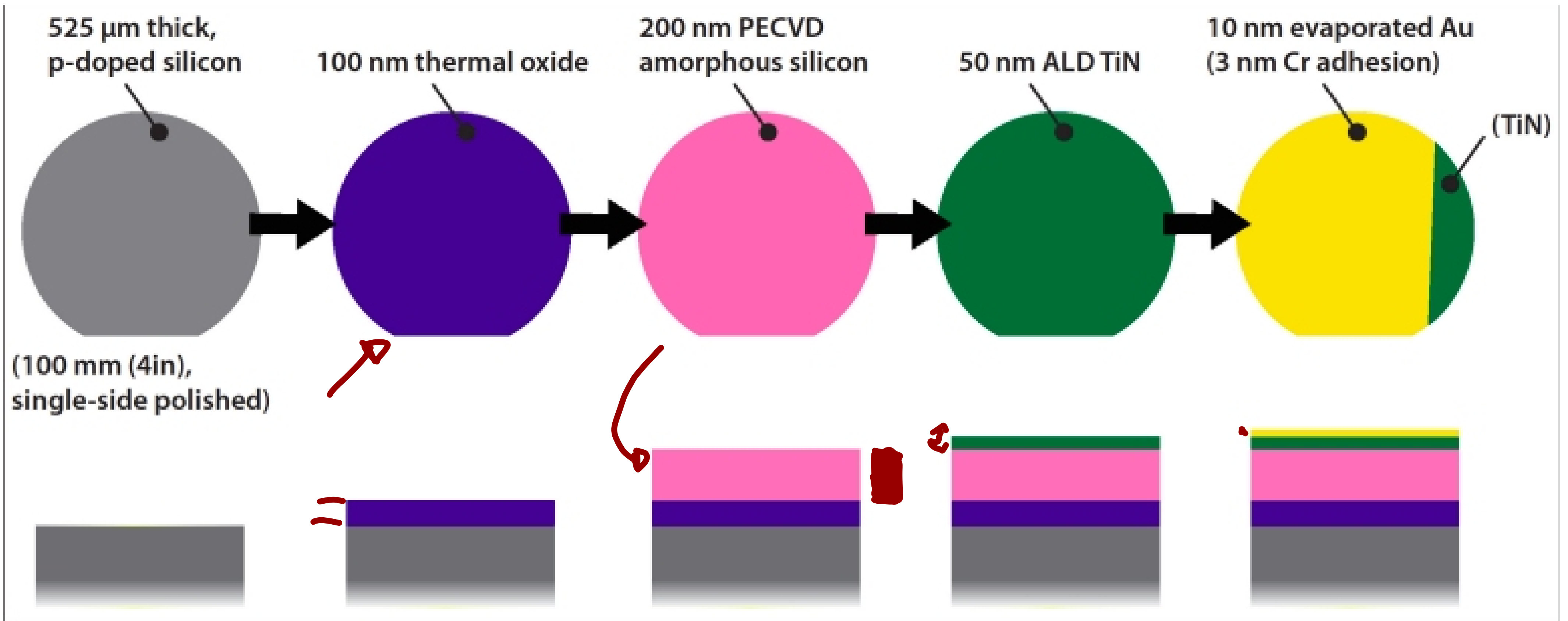


CONCEIVED TO WORK AT WAFER LEVEL

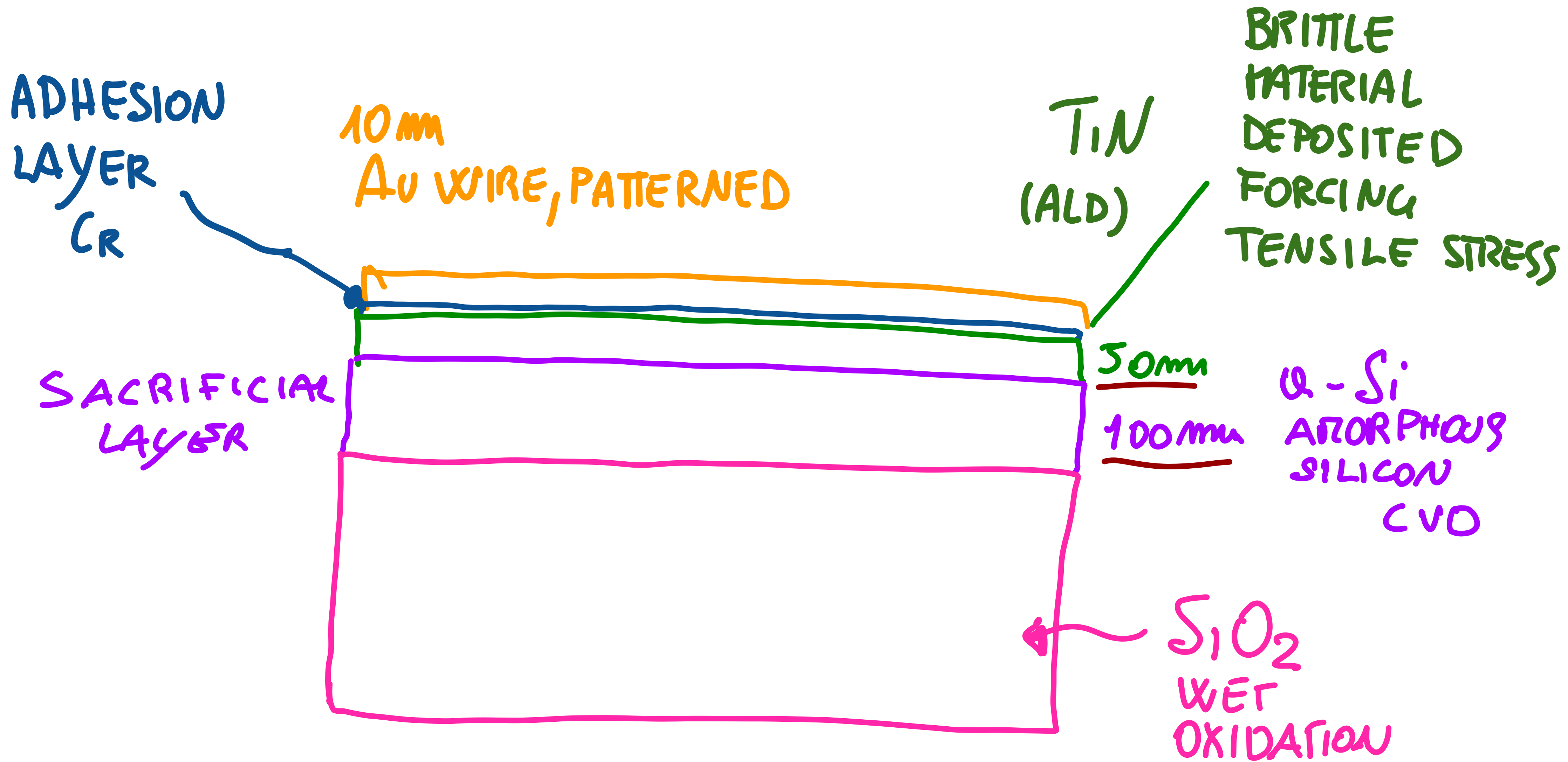
TO GENERATE MANY N.G. IN PARALLEL

↓ NATURE COMMUNICATIONS - (2018) 9:3433 | DOI 10.1038/s41467-018-05785-z

# STEPS



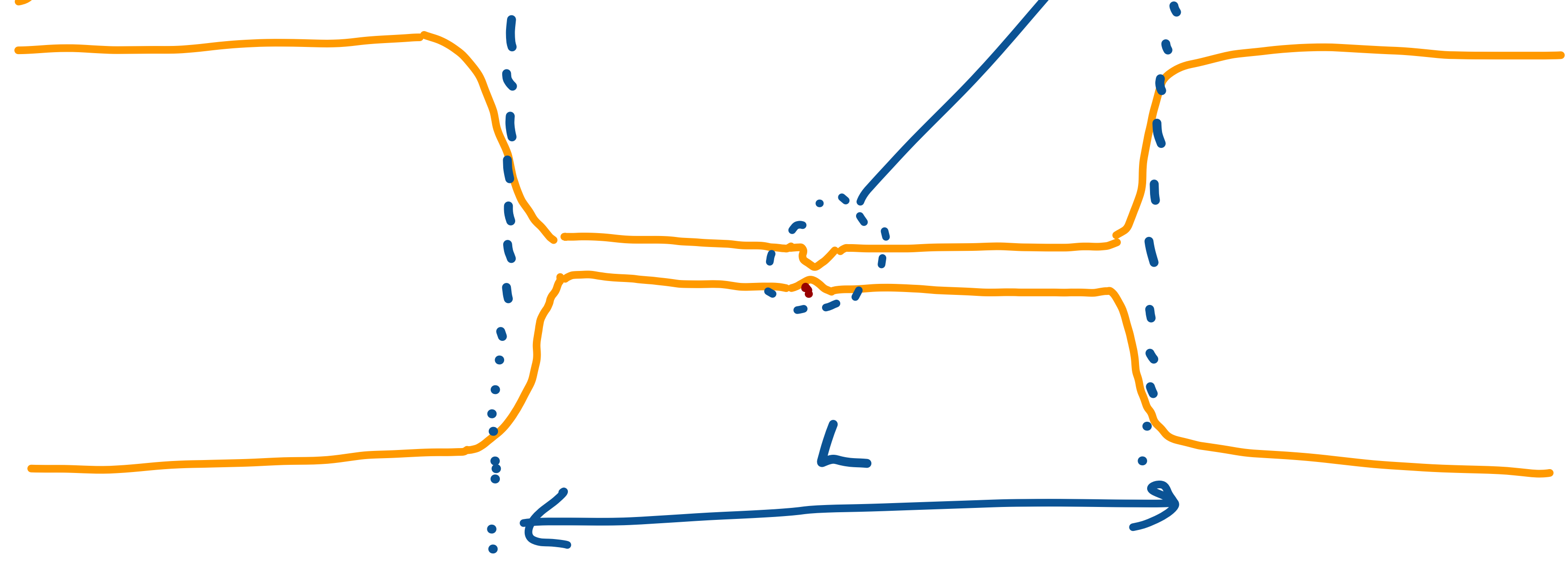
# LAYERS



top view

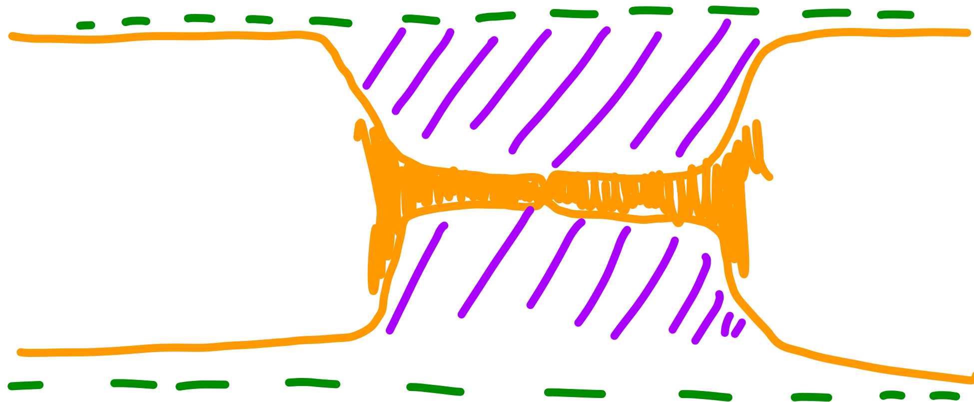
GOLD LAYER

NOTCH WHERE THE GAP IS EXPECTED

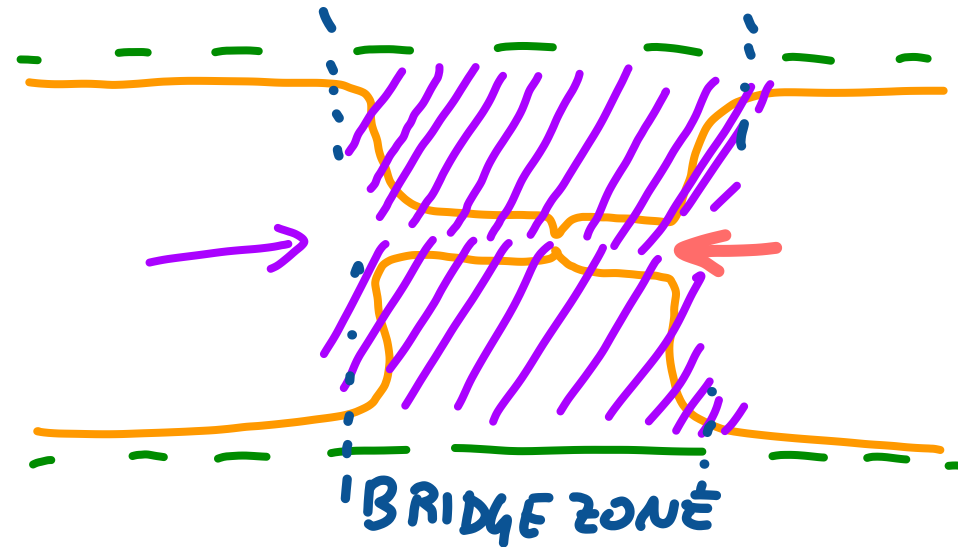



BRIDGE ZONE

# UNDERCUT ETCHING of a-Si @ WAFER LEVEL



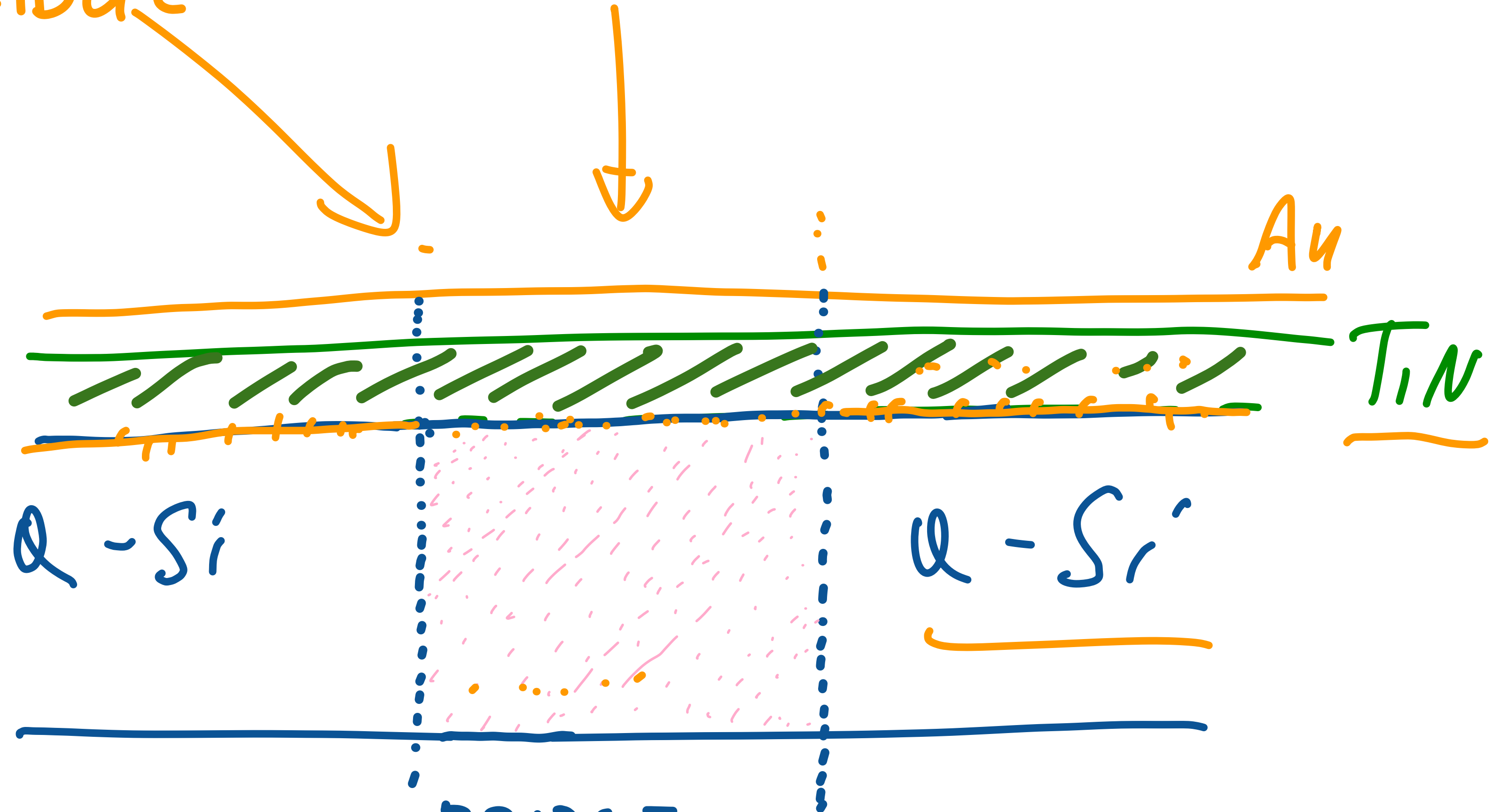
NORMAL ETCHING




UNDERCUT ETCHING

a-Si IS NO MORE PRESENT BELOW THE Au-Cr-TiN BRIDGE

GOLD BRIDGE

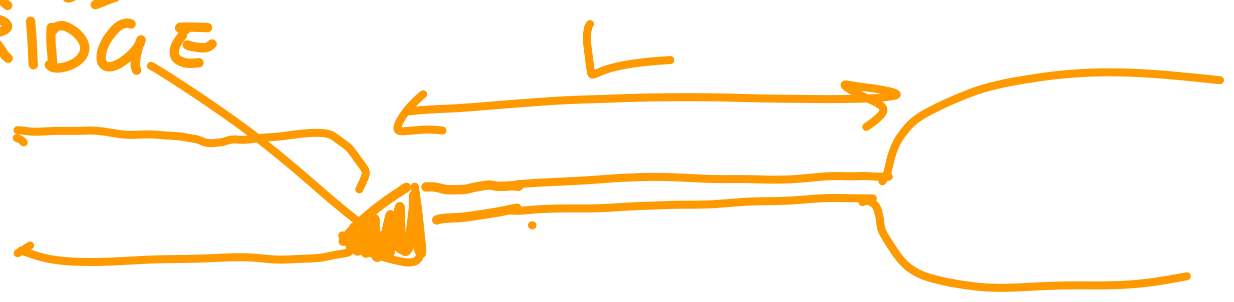



BRIDGE ZONE EXPOSED TO UNDERCUT ETCHING

$SiO_2$

TOP VIEW

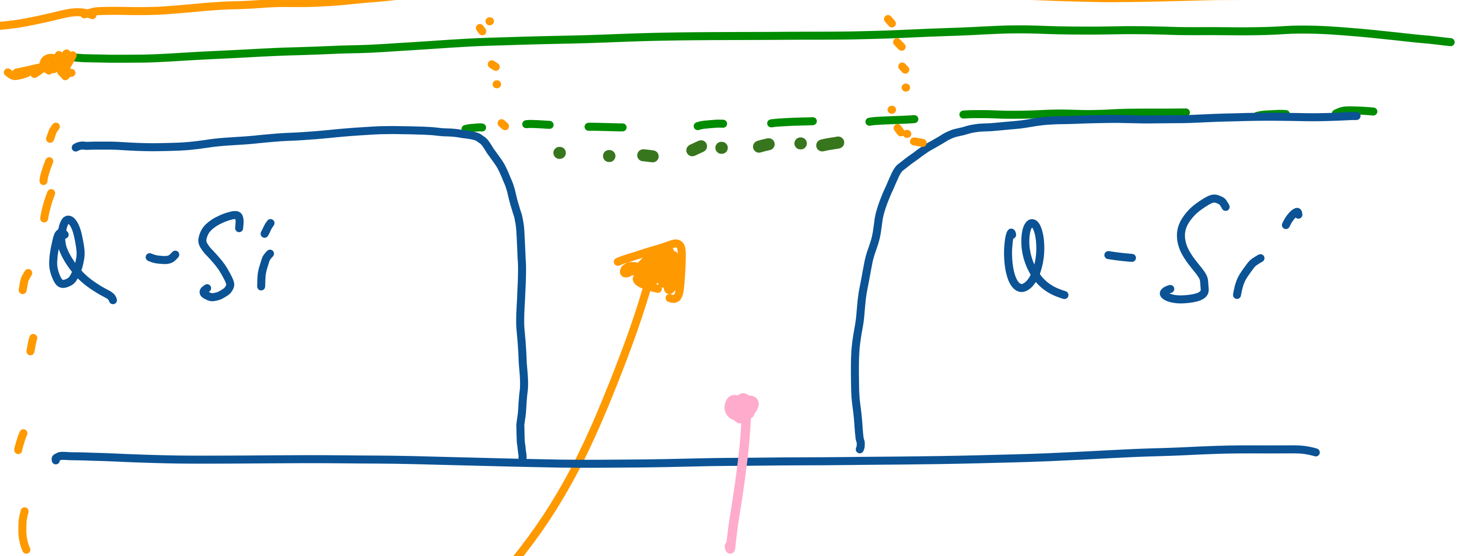
GOLD BRIDGE




Au

TiN

SECTION VIEW

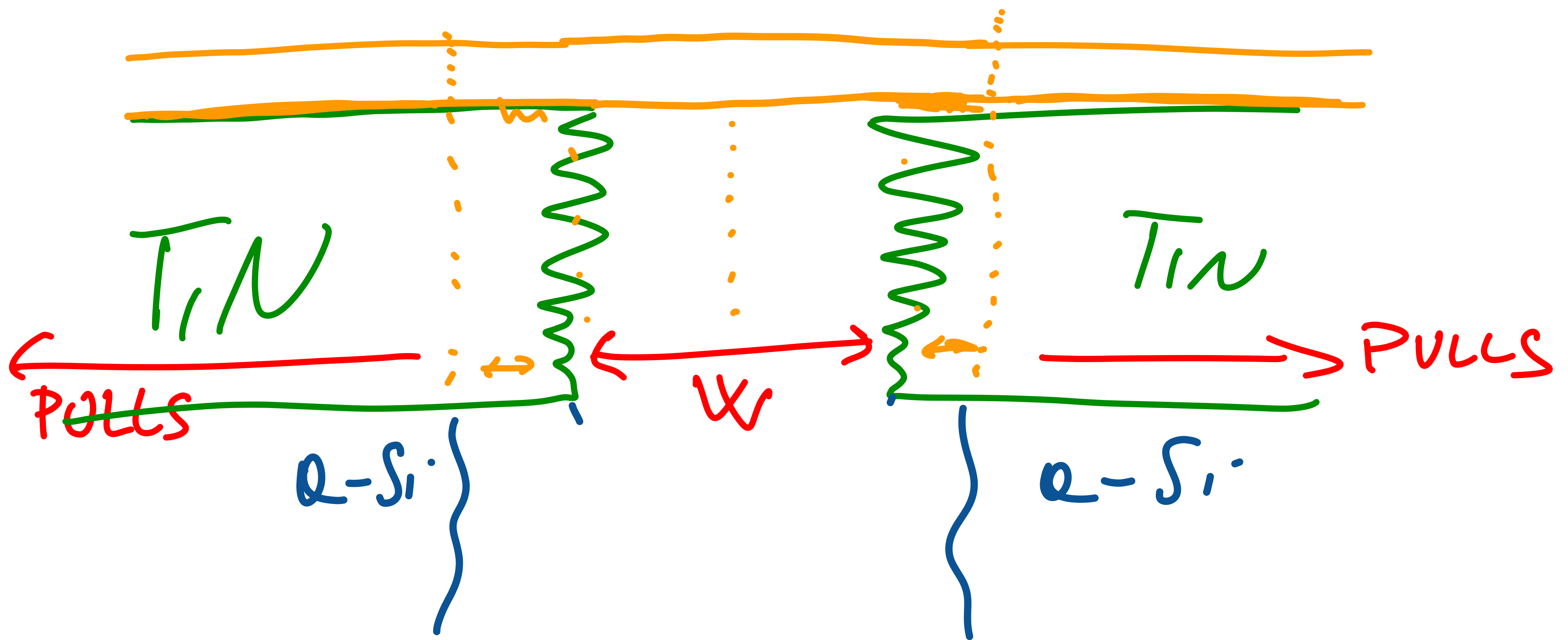



ETCHED ZONE

$SiO_2$

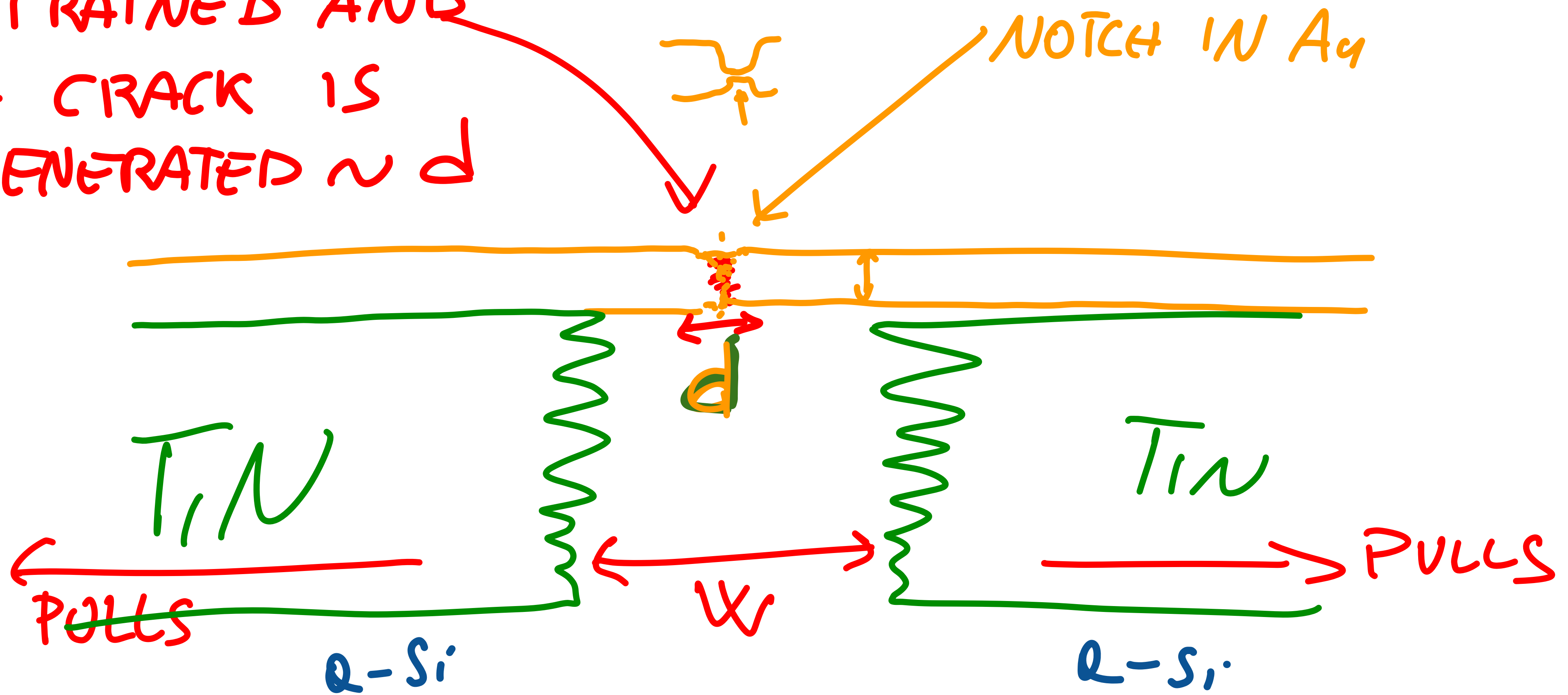
THE VOID OF a-Si INDUCES A CRACK in TiN

TiN LAYER IS CRACKED OPEN TO A SIZE W, DEPENDING ON L




$w = L \times \varepsilon$ ← ELASTIC STRAIN OF TiN ~ 2.7 $\frac{nm}{\mu m}$ (AVERAGE)

THE GOLD NOTCH IS STRAINED AND A CRACK IS GENERATED ~ d

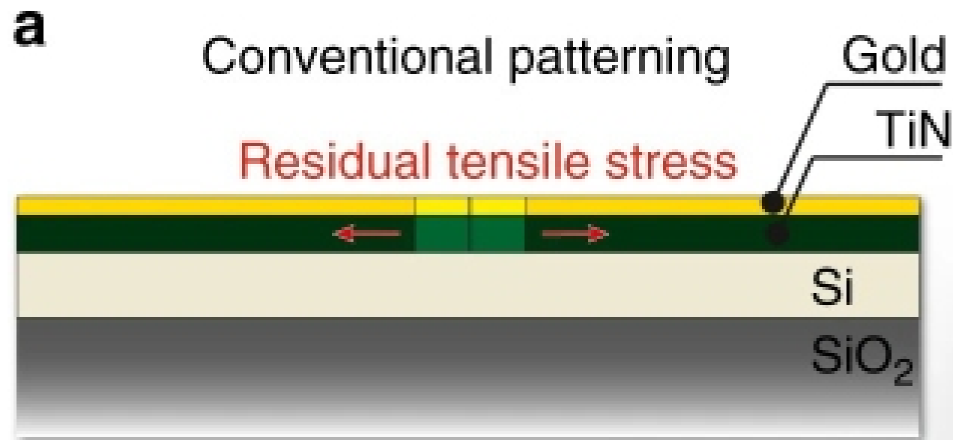


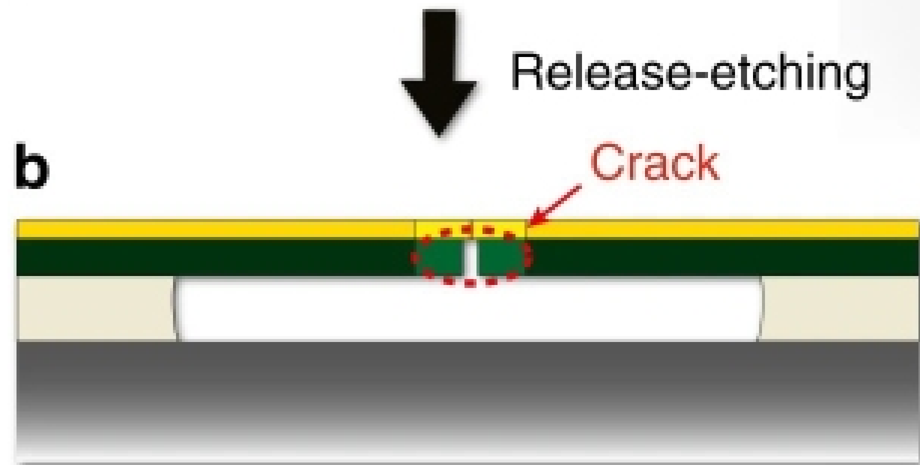

TIN ACTS AS A CANTILEVER, PULLS IN OPPOSITE DIRECTIONS

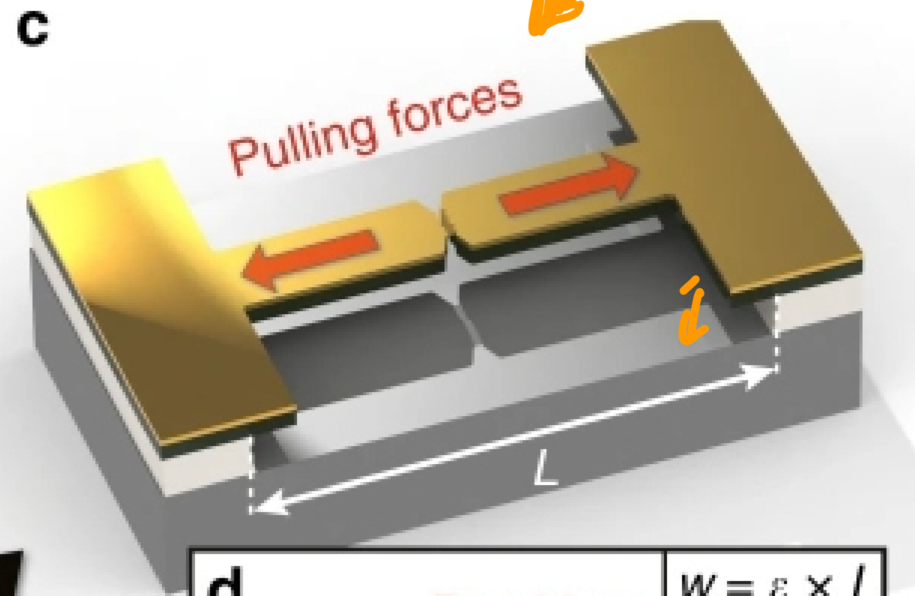
$d \propto .w = L \times \varepsilon$ ← ELASTIC STRAIN OF TiN ~ 2.7 $\frac{mm}{m}$ AVERAGE

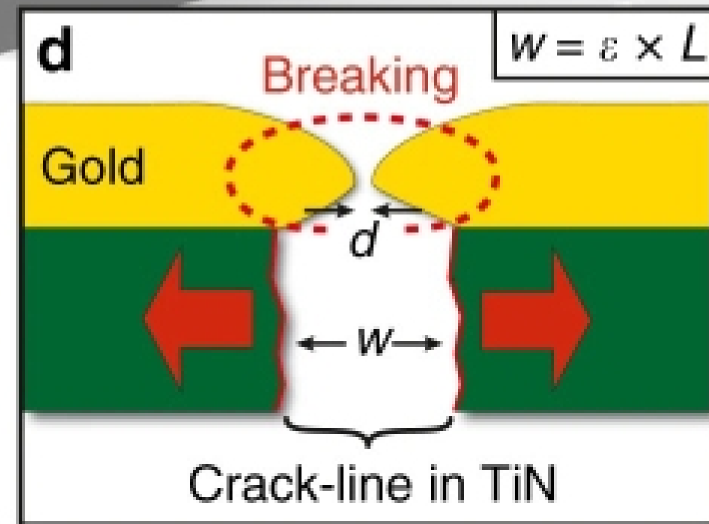
THE RELATION IS NOT MODELED JET

ANOTHER SUMMARY VIEW



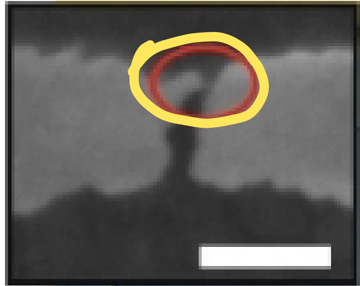



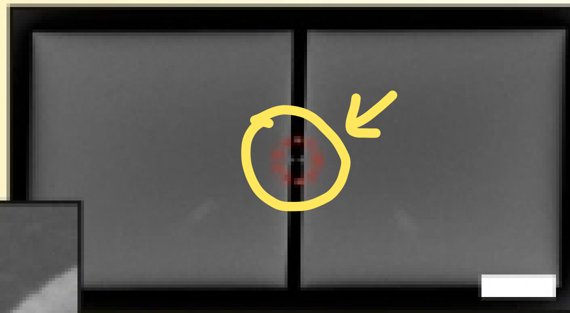



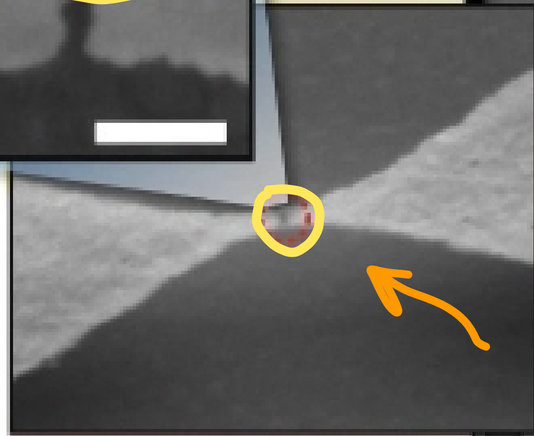
WORKS AT WAFER LEVEL

Nanogap-level $10^{-9}$ m CDBJ-level $10^{-6}$ m Wafer-level $10^{-1}$ m

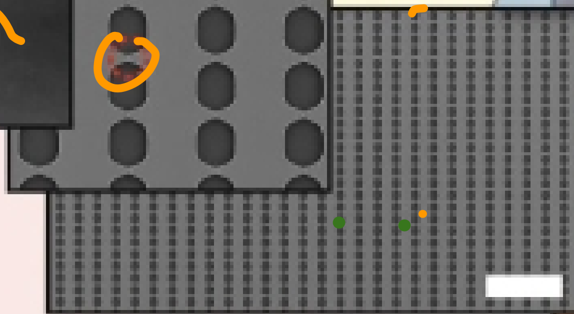
Sub–3 nm gap



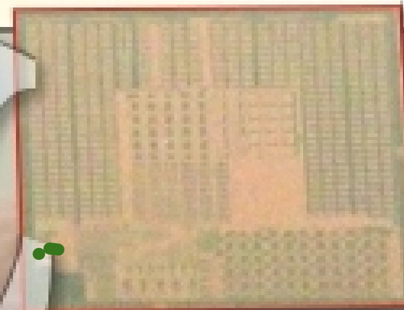


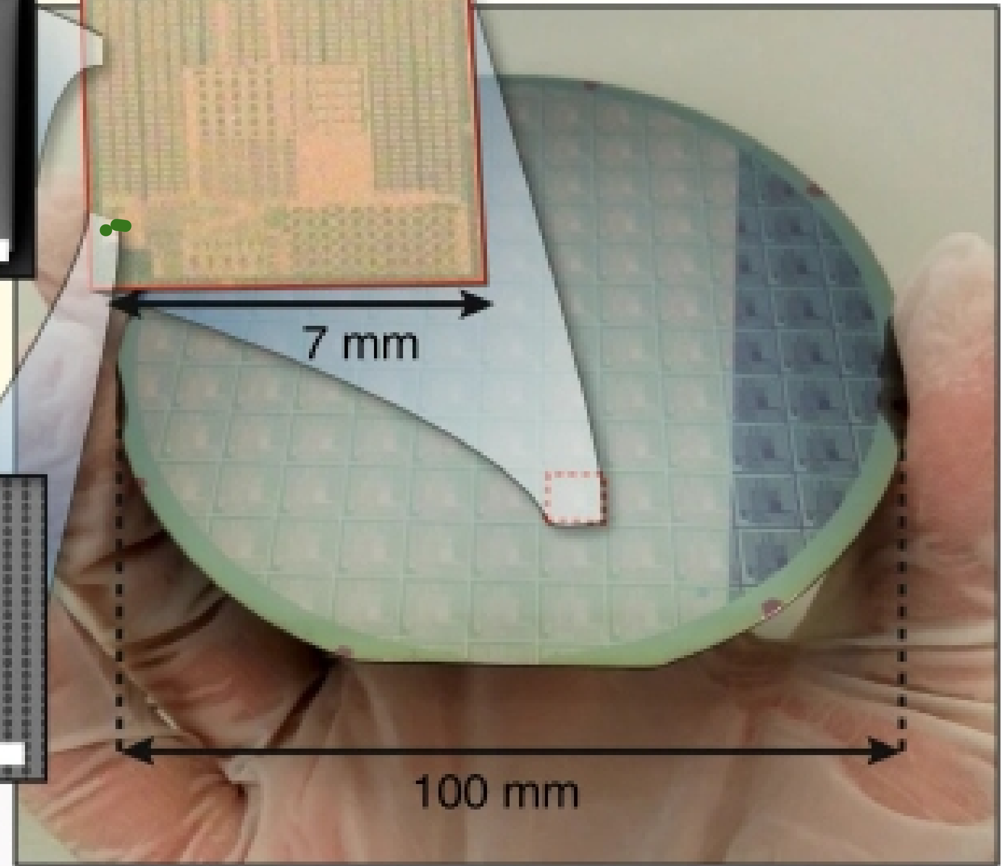


Electrically probable



High-density array






>100,000 break junctions 100 cells 1 wafer

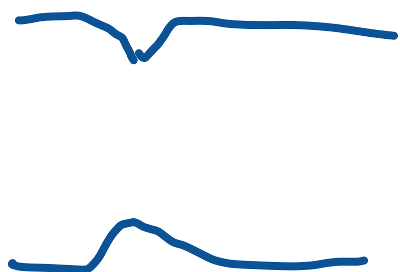
THE METHOD IS SCALABLE

→ 780.000 BRIDGES IN // IN A CHIP

More than 85% of bridges → GAPS

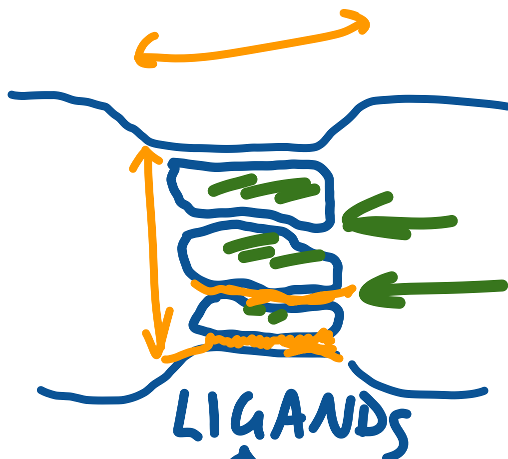
→ GOOD GAPS ~ 3mm GOAL

# GAPS FORMED ARE OF VARIOUS TYPE



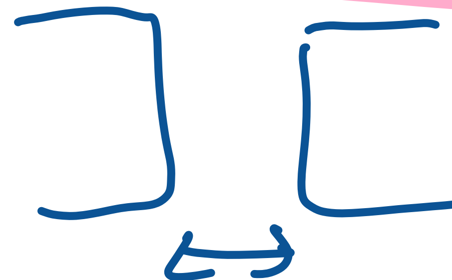
NO GAPS

L < 1 μm



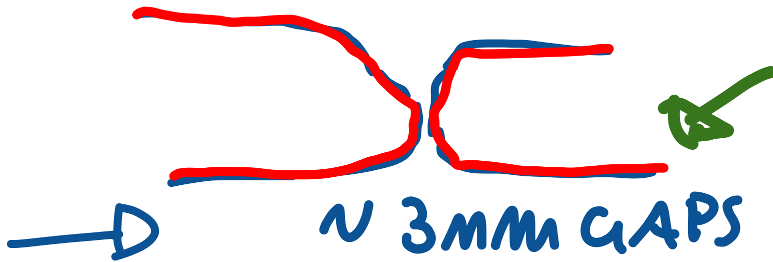

SMALL GAPS

→ NO LIGANDS



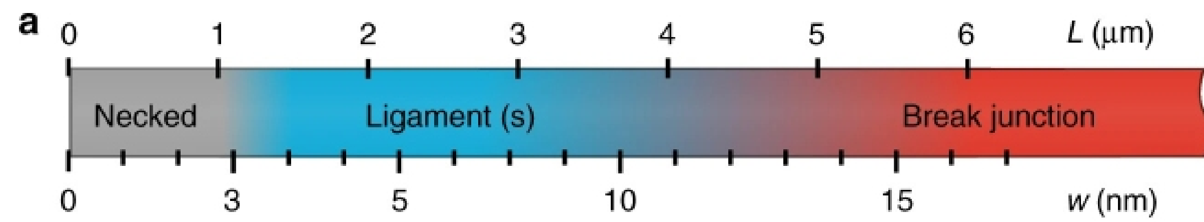
BIG GAPS

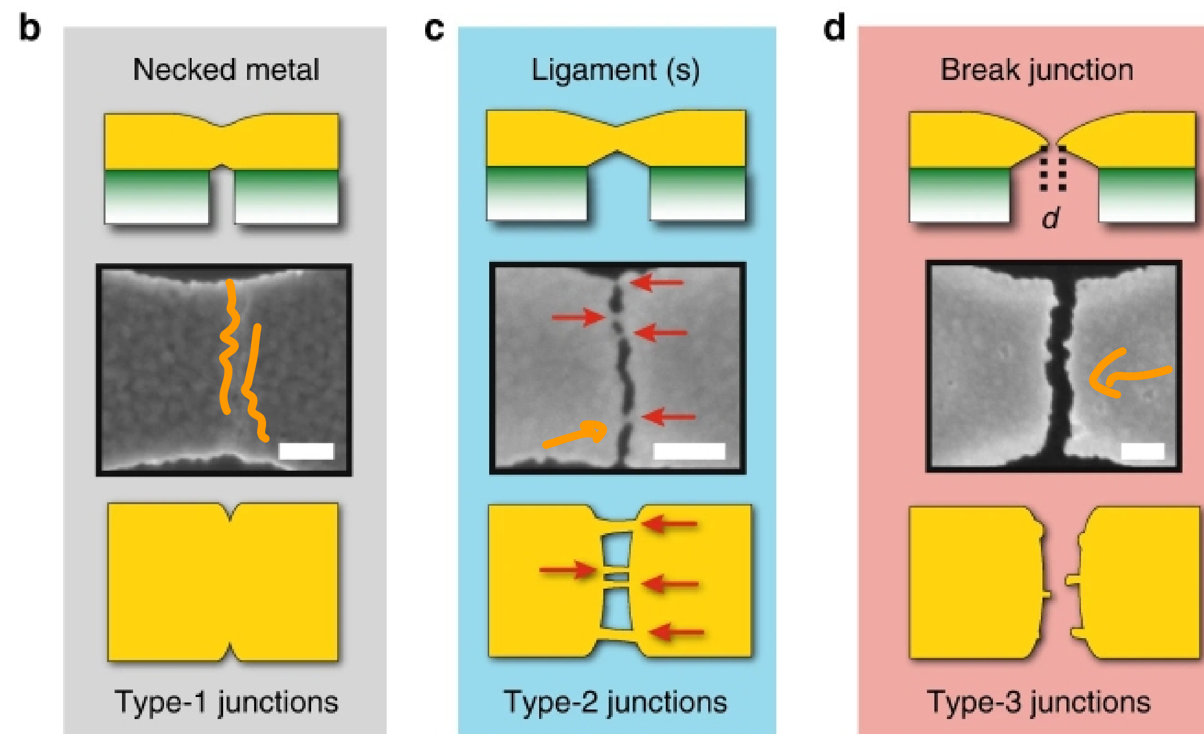
L > 6 μm

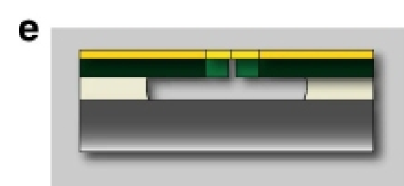


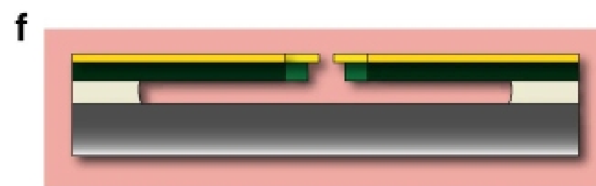
~ 3mm GAPS OR TWO

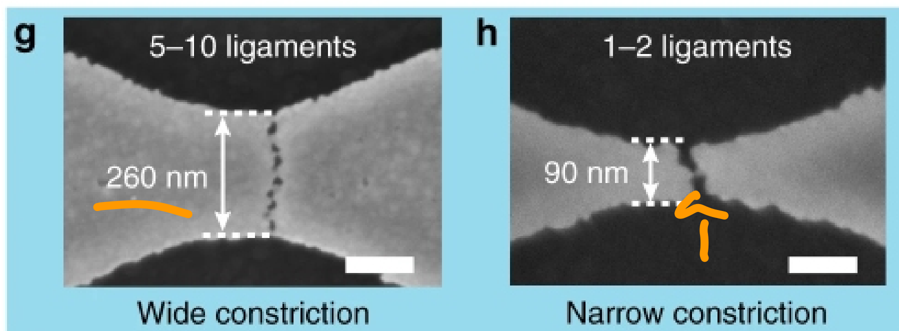
3mm ~ 7-8% YEALDS



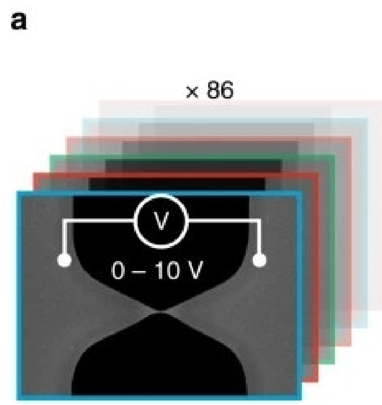



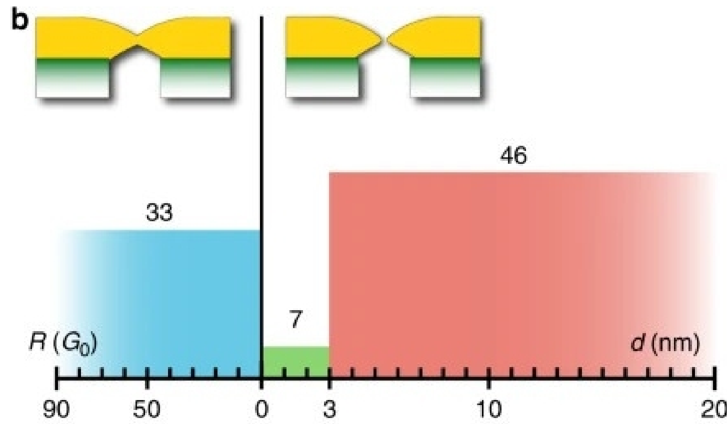




THE RESULTING JUNCTION DEPENDS

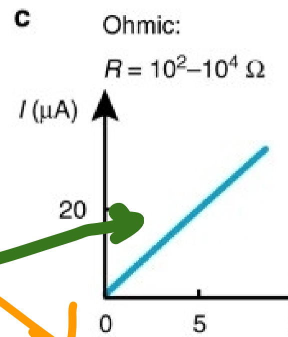
- ON L
- ON TENSILE STRESS
- ON NOTCH SHAPE / SIZE
- MATERIALS

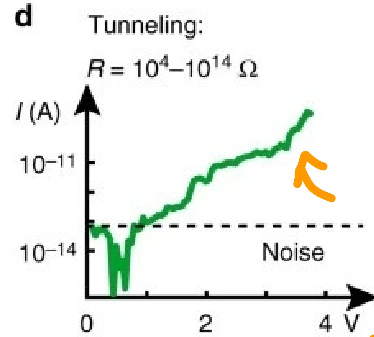


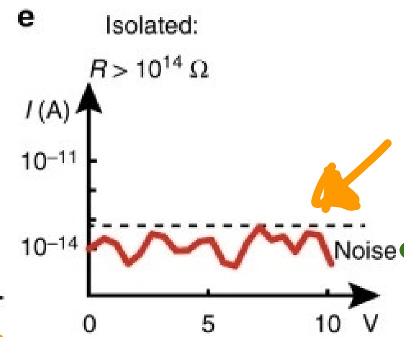




# CHARACTERIZATION

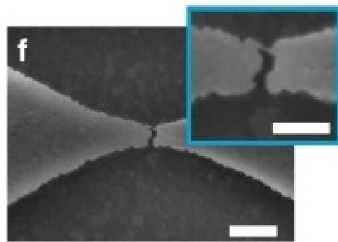
← DISTRIBUTION

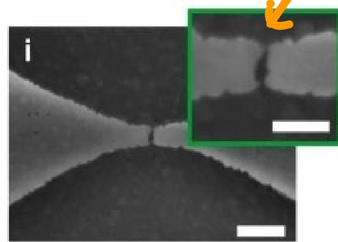


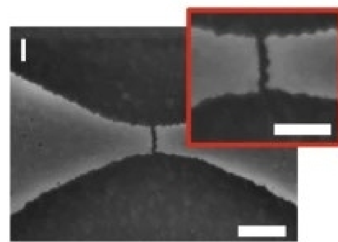



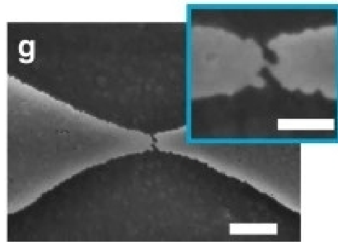



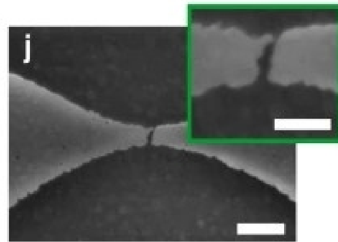

← MEASURED I/V CURVE

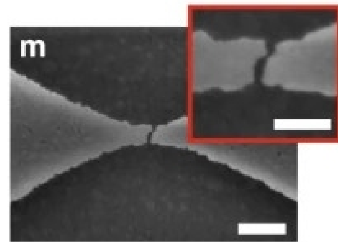


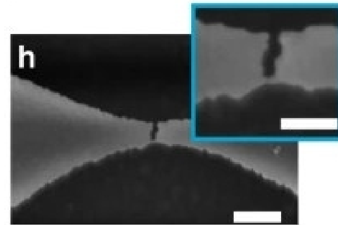



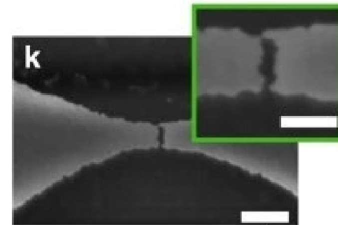



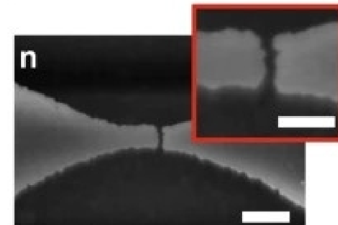




← PHOTOS OF SOME SAMPLES

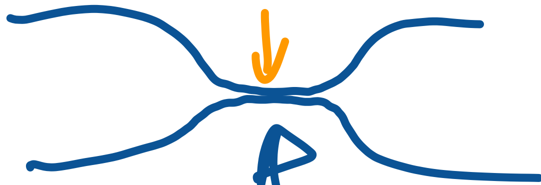
THE TREND of the RESEARCH

↳ CDBJ

↳ END: EM, NO FEEBACK

↓

ON VERY THIN WIRES RESULTING FROM CDBJ CANTILEVER



(C) STAL

SIZE-TUNABLE ADHESION LITHOGRAPHY ]

CONCEIVED FOR MASSIVE PARALLEL AND TUNABLE GENERATION

ADVANCED MATERIAL | DOI: 10.1002/adma.202100491

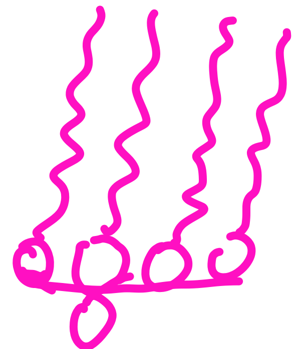
M1 DEPOSITED ON SUBSTRATE, PATTERNED AS NEEDED

THE LAYER THICKNESS CORRESPONDS TO THE MOLECULE HEIGHT

M1 SELECTIVELY COATED WITH A METALLOPHILIC SELF-ASSEMBLED-MONOLAYER (SAM)

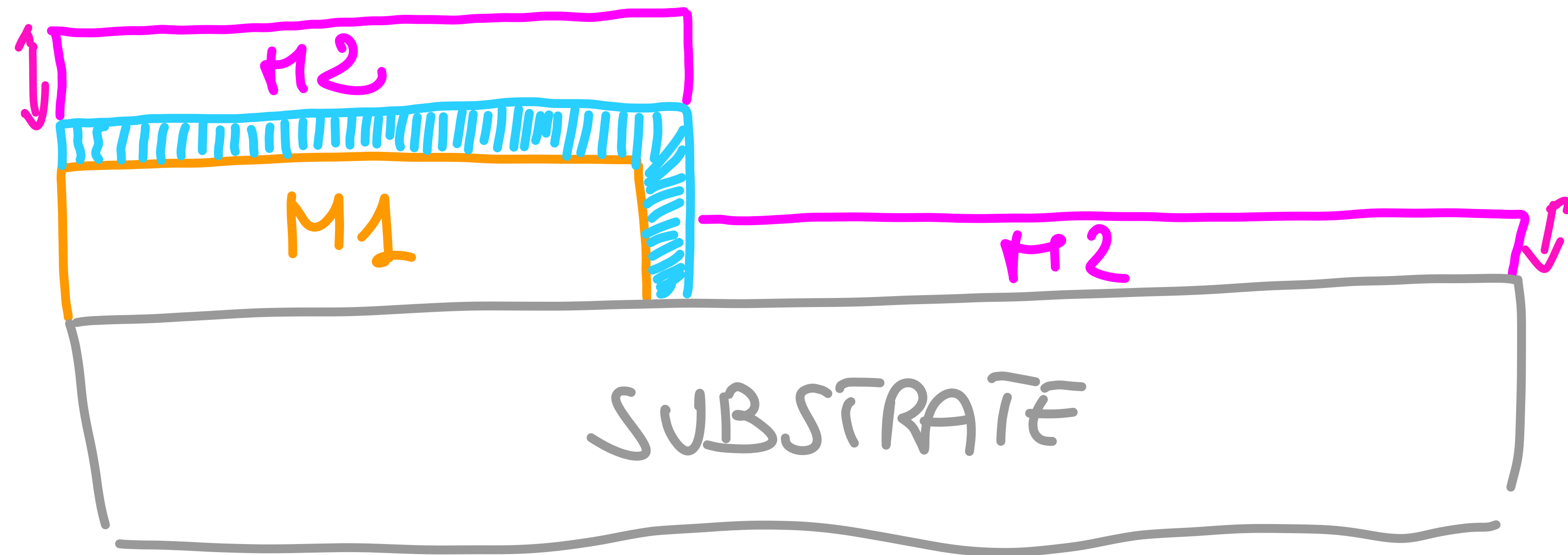
M1

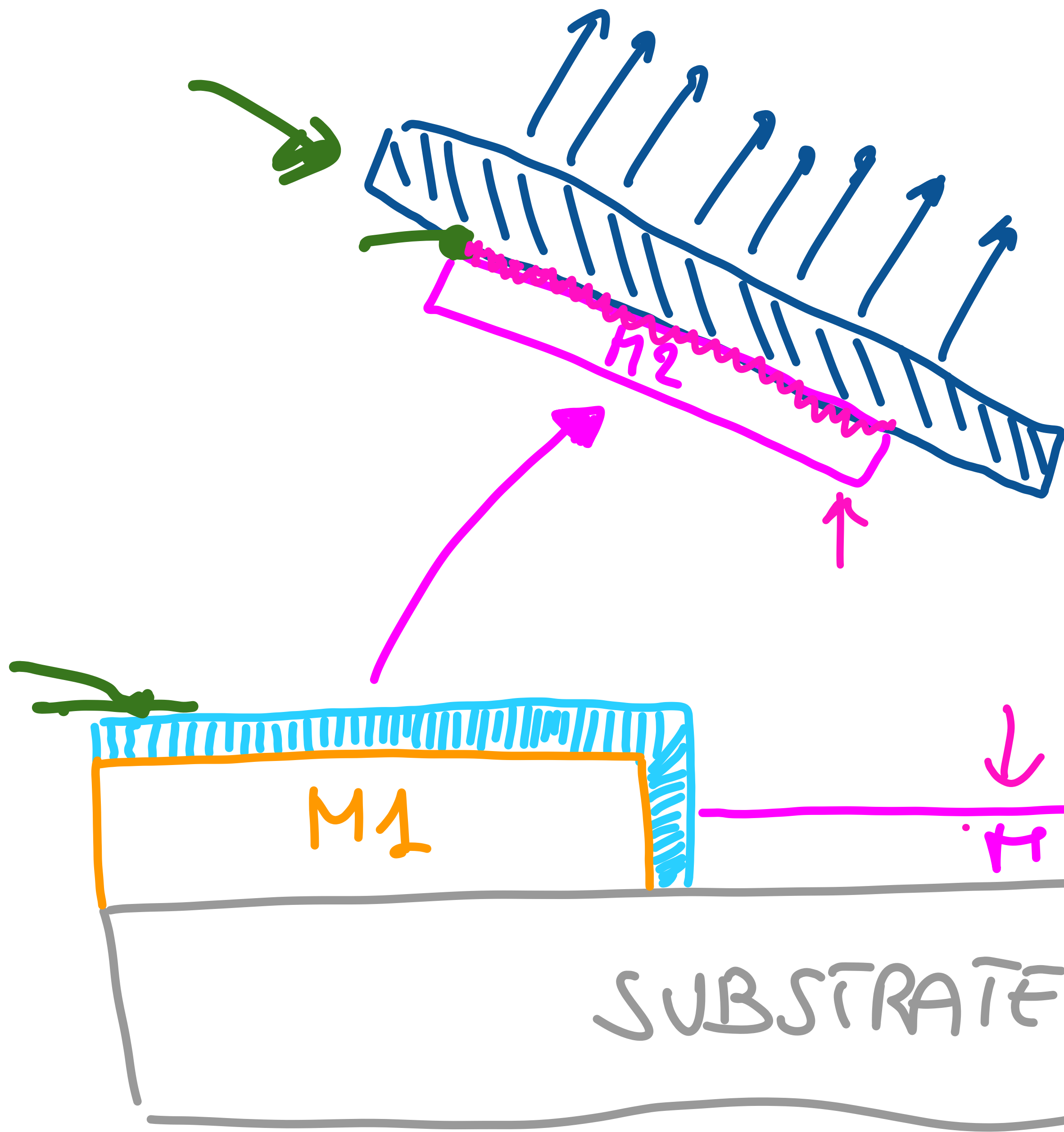
SUBSTRATE



$t_{K_{M2}} \leq t_{K_{M1}}$

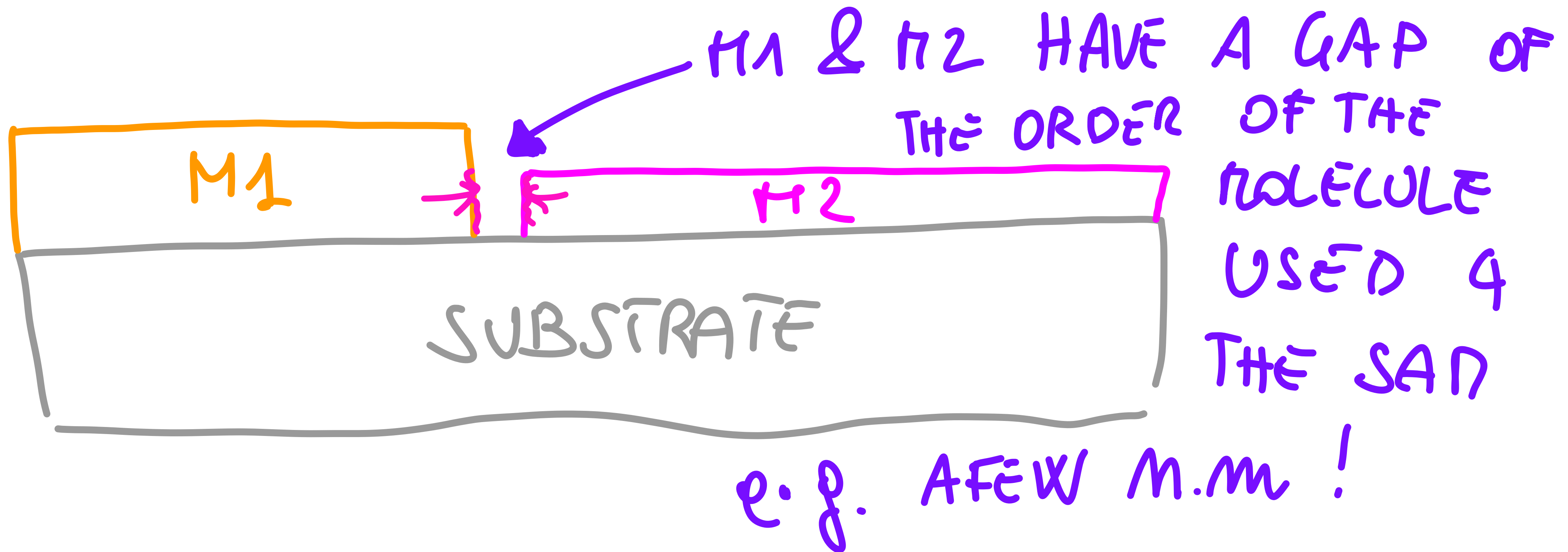
M2 IS DEPOSITED ON THE SAM AND ON THE EXPOSED SUBSTRATE



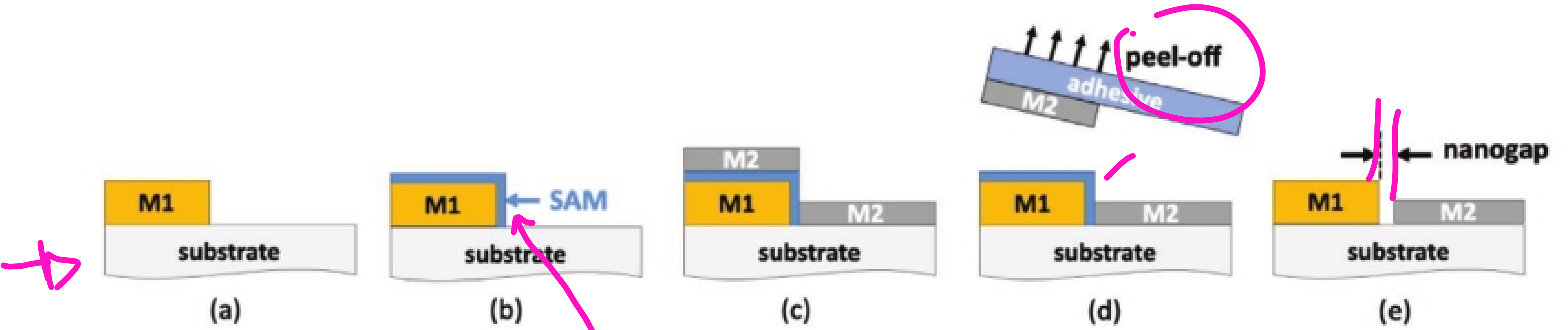


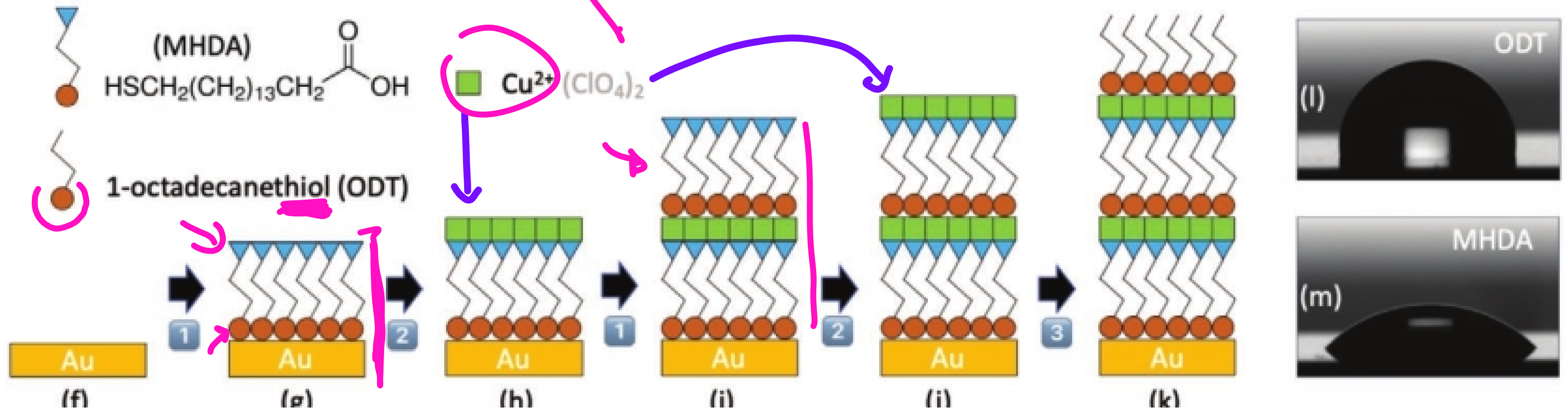

AN ADHESIVE FILM APPLIED TO M2 SURFACE AND PEELED AWAY SELECTIVELY FROM THE SAM ZONES ONLY

THE SAM IS REMOVED USING OZONE OR UV OR OXIGEN PLASMA @ A CONTROLLED T.



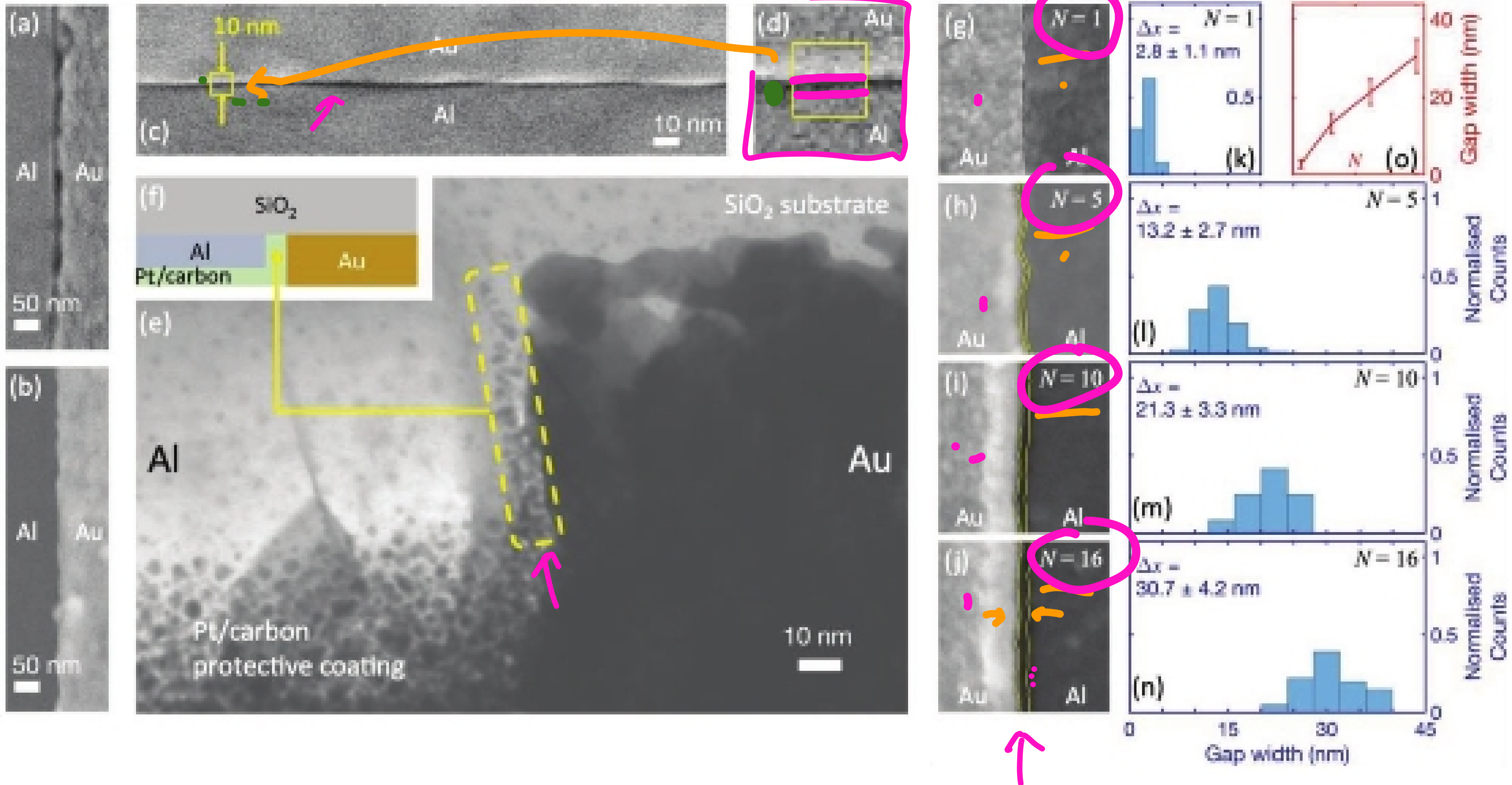
# PROCEDURES OVERVIEW




THE SAM CAN BE PROGRESSIVELY INCREASED IN HEIGHT → THE GAP THICKNESS IS "PROGRAMMED"

DEMONSTRATION OF INCREASING GAP SIZE PROPORTIONAL TO INCREASED N. OF STACKED MOLECULES



- → VERY NOVEL
- → INTERESTING FOR
  - → PARALLEL AND MASSIVE APPROACH
  - → VERY CHEAP
  - → MOLECULE SIZE CAN BE SELECTED
  - → N° OF STACKED MOL CAN BE SELECTED
- → PEELING IS THE CRITICAL PART ...

# CRISTALLIZATION

- MCBJ
- CDBJ
- STAL
- FIB
- EM (FCE)