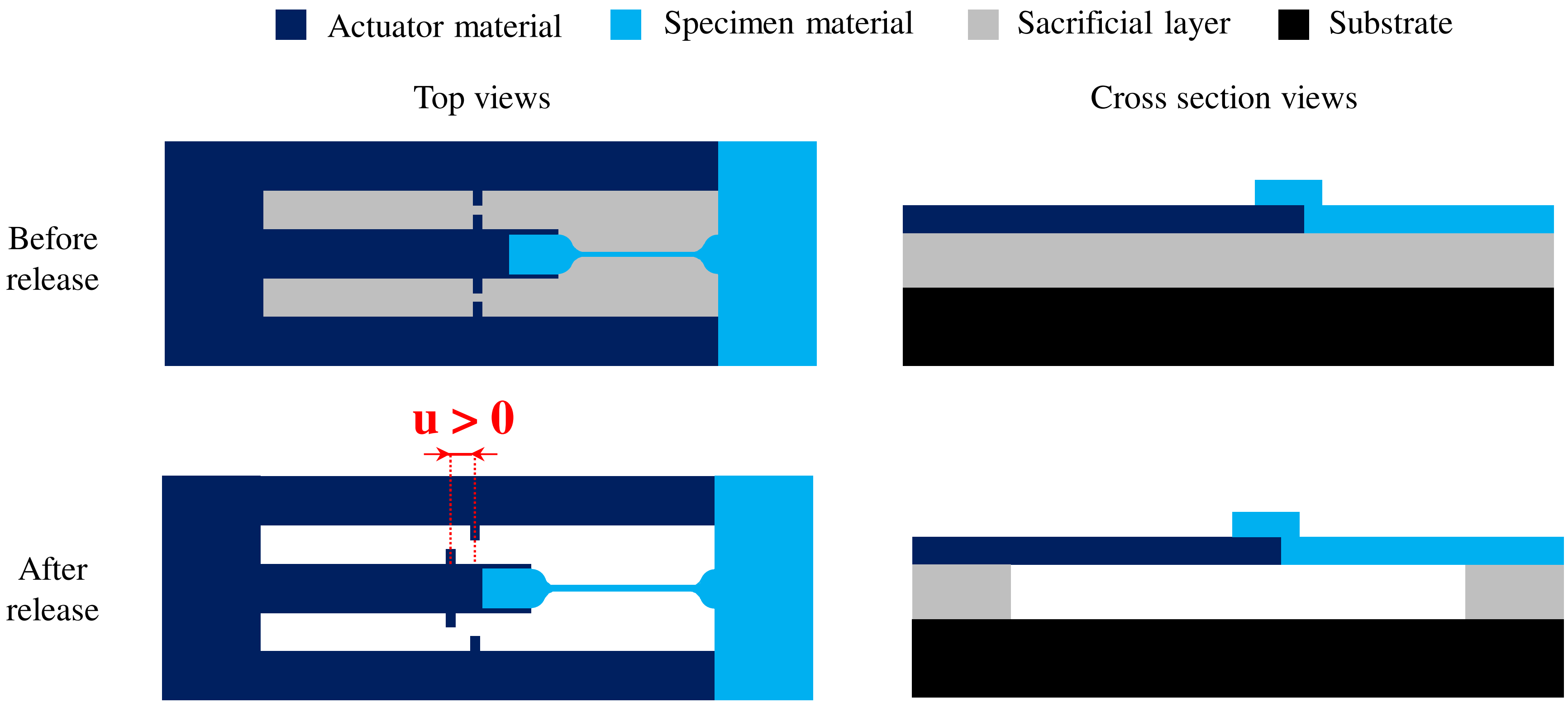
Uniaxial on-chip tensile testing – *Principle*

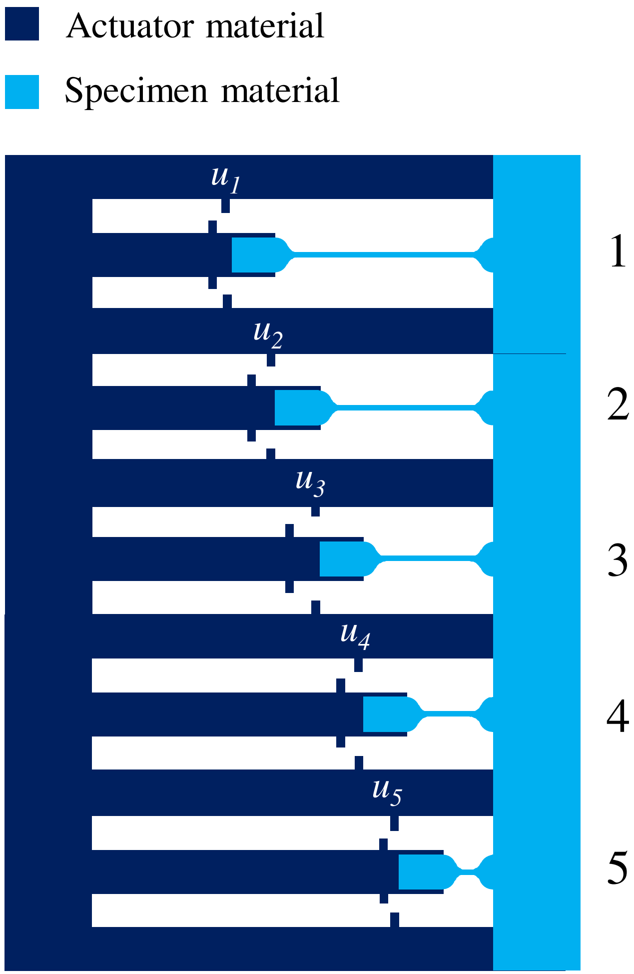
MEMS-based structure with an 'on-chip' actuation

Key concept: use the internal stress generated during the deposition of an actuator material to pull on another specimen material

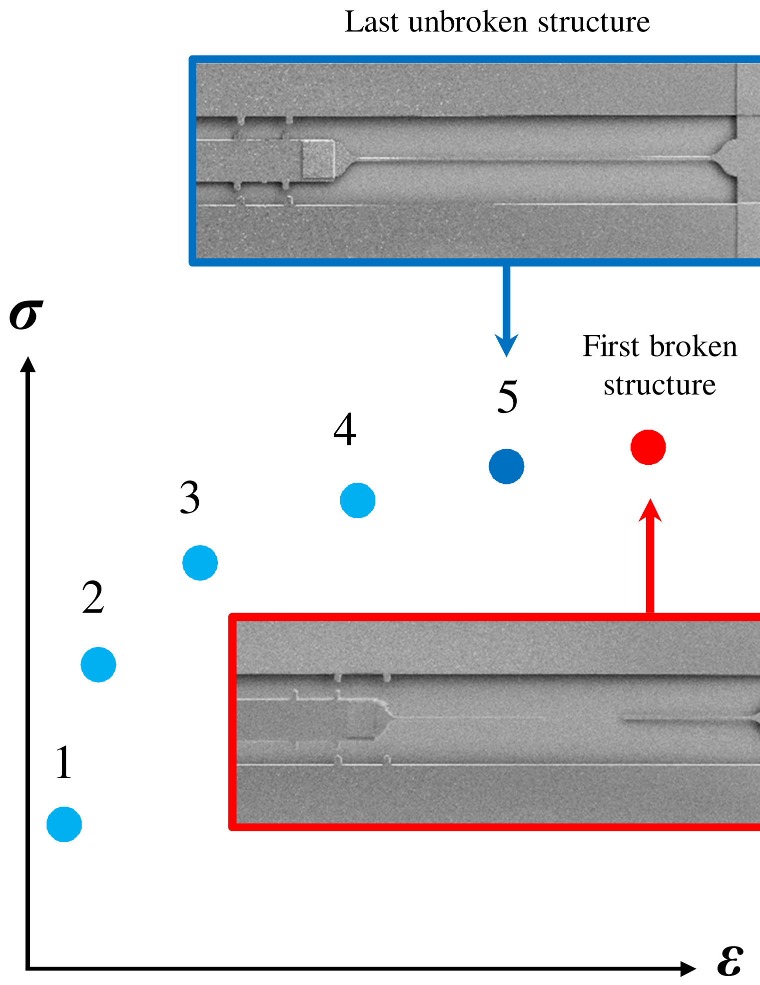


From the measurement of u and the use of an analytical model, one point of the Stress – Strain curve is extracted

Uniaxial on-chip tensile testing – *Principle*



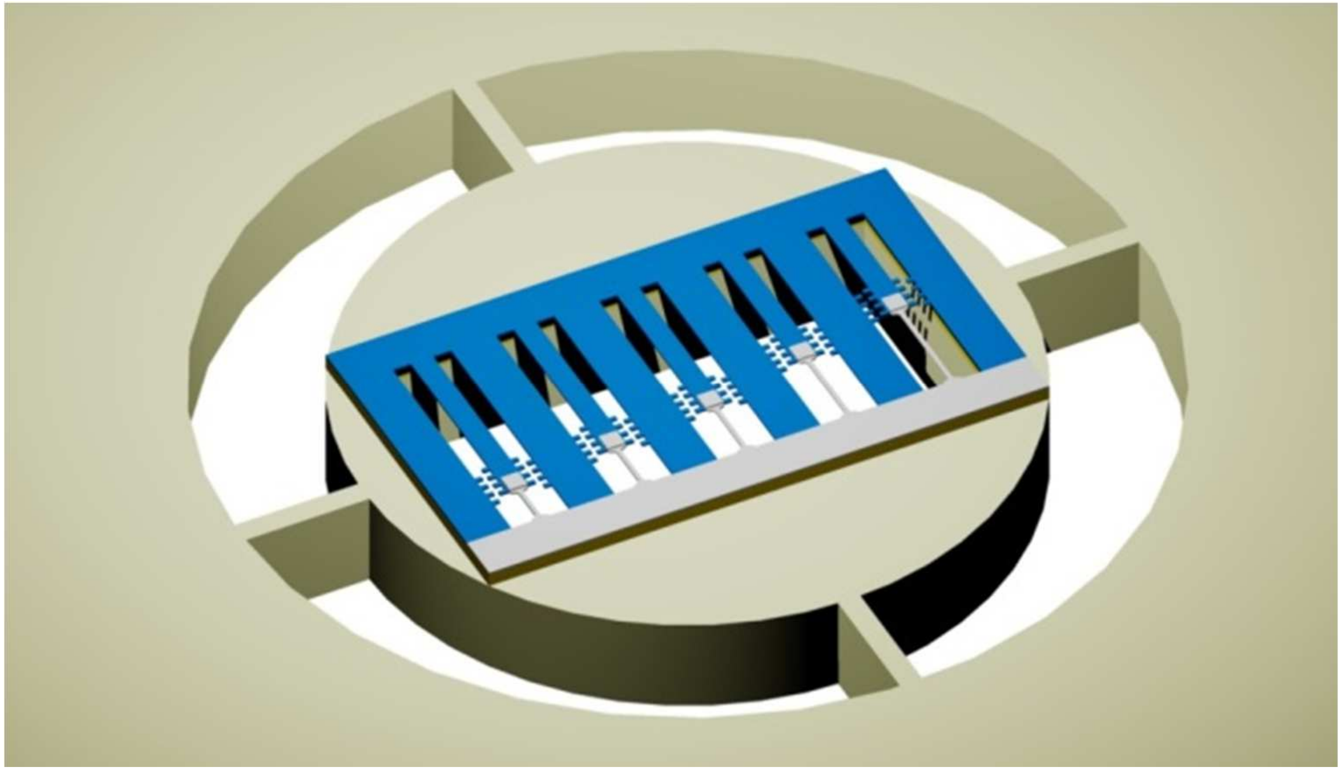
u_1, u_2, ...



Discrete Stress - Strain curve

The discrete Stress - Strain curve is obtained by changing the in-plane dimensions of both, the actuator and specimen beams

Uniaxial on-chip tensile testing – *In-situ TEM observation*



Back-etching of the silicon susbtrate allowing the in-situ TEM analysis of the fundamental mechanisms of deformation

Classic process – *Cleaning and measurement steps are not included*

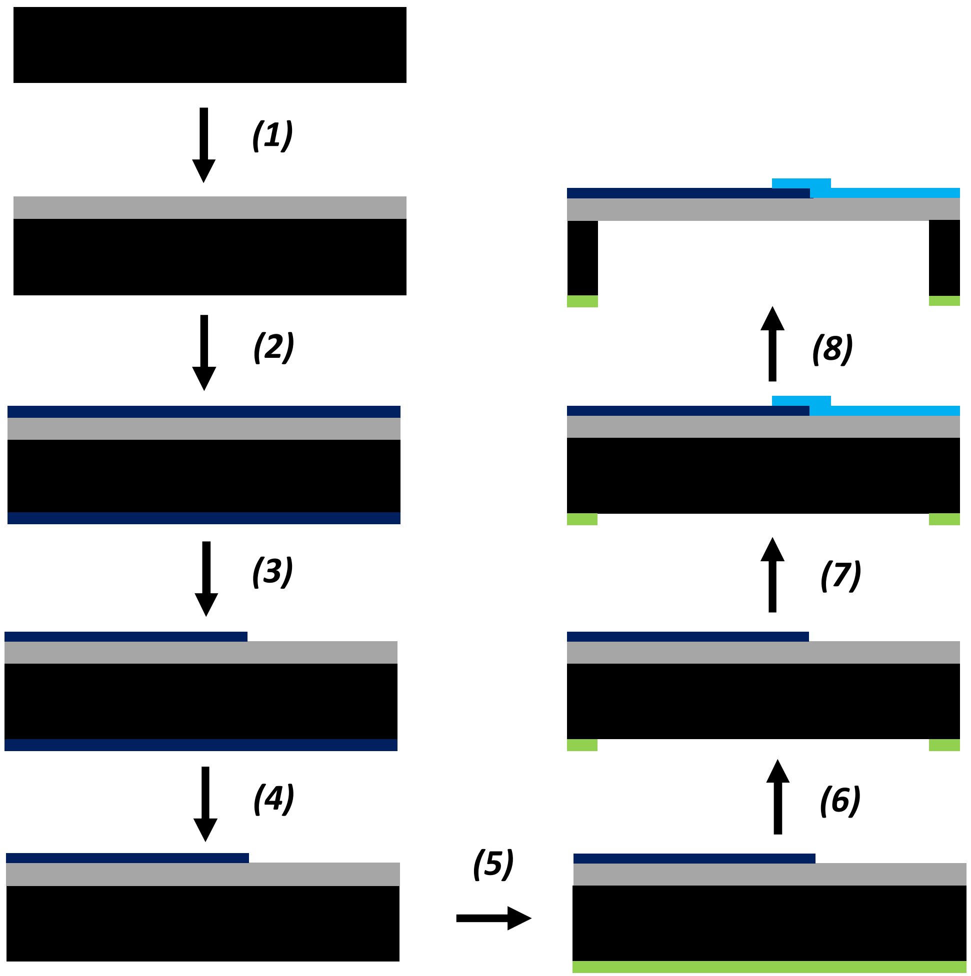
Si substrate

Hard mask - Si_3N_4, SiO_2, Al, specific resist, …

Sacrificial layer - PECVD SiO_2

Actuator material - LPCVD Si_3N_4

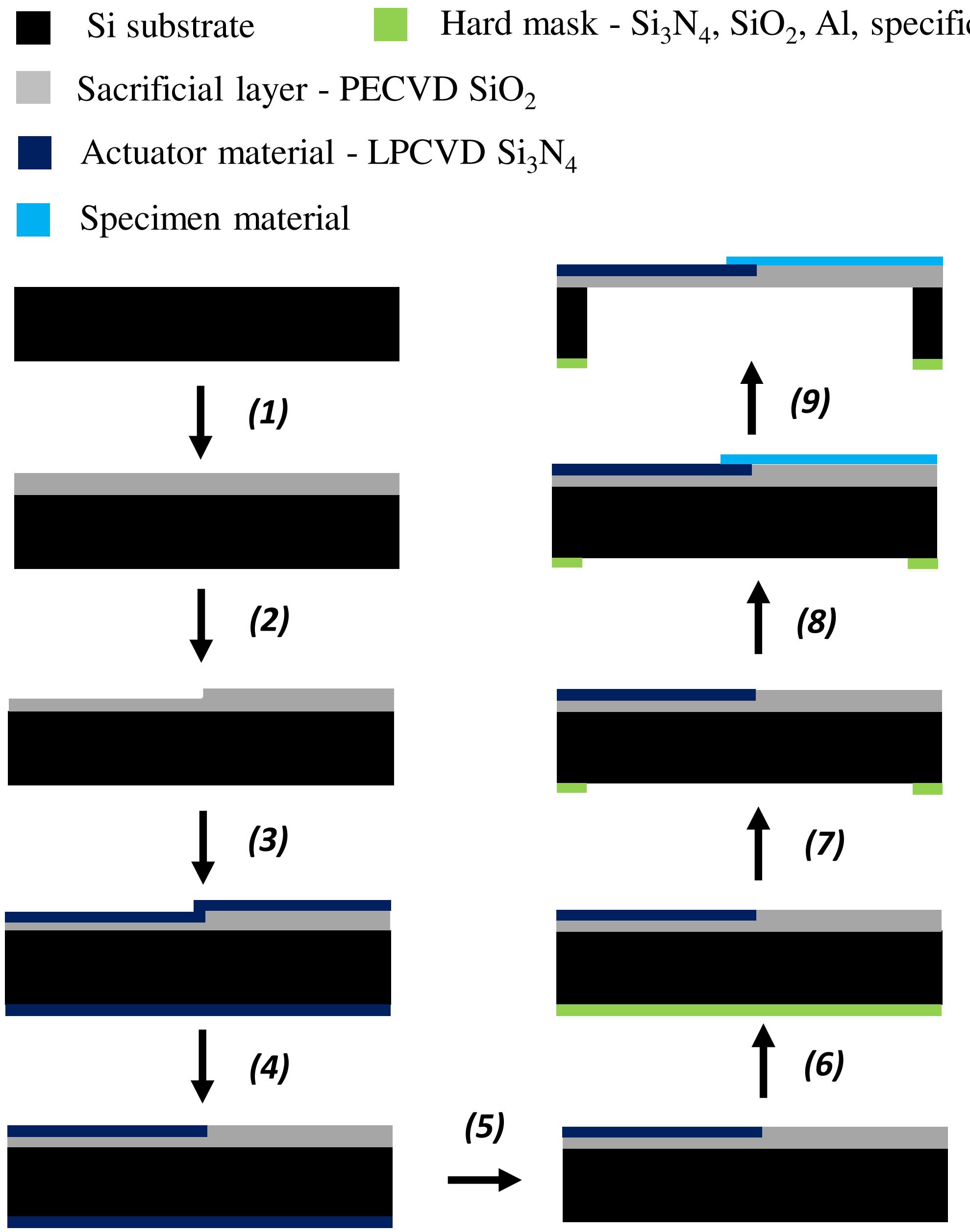
Specimen material



1. Front side deposition of 1 – 2 μm PECVD SiO_2
2. Deposition of LPCVD Si_3N_4 (30 – 300 nm) with a high tensile stress (~1 GPa)
3. Front side coating of positive resist + Front side photolithography + Front side SF_6 plasma etching of LPCVD Si_3N_4 + Front side resist removal
4. Front side coating of protective resist + Back side SF_6 plasma etching of LPCVD Si_3N_4
5. Back side depostion of hard mask (Si_3N_4, SiO_2, Al, resist, …)
6. Patterning of hard mask + Front side resist removal
7. Front side coating of reversal resist + Front side photolithography + Deposition of the specimen material by evaporation or sputtering (40 – 200 nm) + Lift off
8. Deep RIE of Si substrate (Bosch process) with stop on PECVD SiO_2

Rmq: depending on the nature of hard mask, the steps 5/6 and 7 can be inverted

Alternative process – *Cleaning and measurement steps are not included*



1. Front side deposition of 1 – 2 µm PECVD SiO_2
2. Front side coating of positive resist + Front side photolithography + CF_4 or CHF_3 plasma etching of PECVD SiO_2
3. Deposition of LPCVD Si_3N_4 (30 – 300 nm) with a high tensile stress (~1 GPa)
4. Front side CMP with stop on LPCVD Si_3N_4
5. Front side coating of protective resist + Back side SF_6 plasma etching of LPCVD Si_3N_4
6. Back side depostion of hard mask (Si_3N_4, SiO_2, Al, resist, …)
7. Patterning of hard mask + Front side resist removal
8. Front side coating of reversal resist + Front side photolithography + Deposition of the specimen material by evaporation or sputtering (40 – 200 nm) + Lift off
9. Deep RIE of Si substrate (Bosch process) with stop on PECVD SiO_2

Rmq: depending on the nature of hard mask, the steps 6/7 and 8 can be inverted

Patent

T. Pardoen, D. Fabrègue, J.-P. Raskin, N. André, M. Coulombier, *Internal stress actuated micro- and nanomachines for testing physical properties of micro- and nano-sized material samples*, Publication number: EP19873366 (A2)

Some publications

D. Fabrègue, N. André, M. Coulombier, J.-P. Raskin, T. Pardoen, *Multipurpose nanomechanical testing machines revealing the size-dependent strength and high ductility of pure aluminium submicron films*, Micro & Nano Letters, Vol. 2, 1, p. 13-16 (2007)

S. Gravier, M. Coulombier, A. Safi, N. André, A. Boé, J.-P. Raskin, T. Pardoen, *New on-chip nanomechanical testing laboratory - applications to aluminum and polysilicon thin films*, IEEE Journal of Microelectromechanical Systems, Vol. 18, 3, p. 555-569 (2009)

H, Idrissi, B, Wang, M.-S. Colla, J.- P. Raskin, D. Schryvers, and T. Pardoen, *Ultrahigh Strain Hardening in Thin Palladium Films with Nanoscale Twins*, Advanced Materials, Vol. 23, p. 2119-2122 (2011)

M. Coulombier, G. Guisbiers, M.-S. Colla, R. Vayrette, J.-P. Raskin, and T. Pardoen, *On-chip stress relaxation testing method for freestanding thin film materials*, Review of Scientific Instruments, Vol. 83, p. 105004-1-9 (2012)

M.-S. Colla, B. Amin-Ahmadi, H. Idrissi, L. Malet, S. Godet, J.-P. Raskin, D. Schryvers & T. Pardoen, *Dislocation-mediated relaxation in nanograined columnar palladium films revealed by on-chip time-resolved HRTEM testing*, Nature Communications, Vol. 6, p. 5922-1-8 (2015)