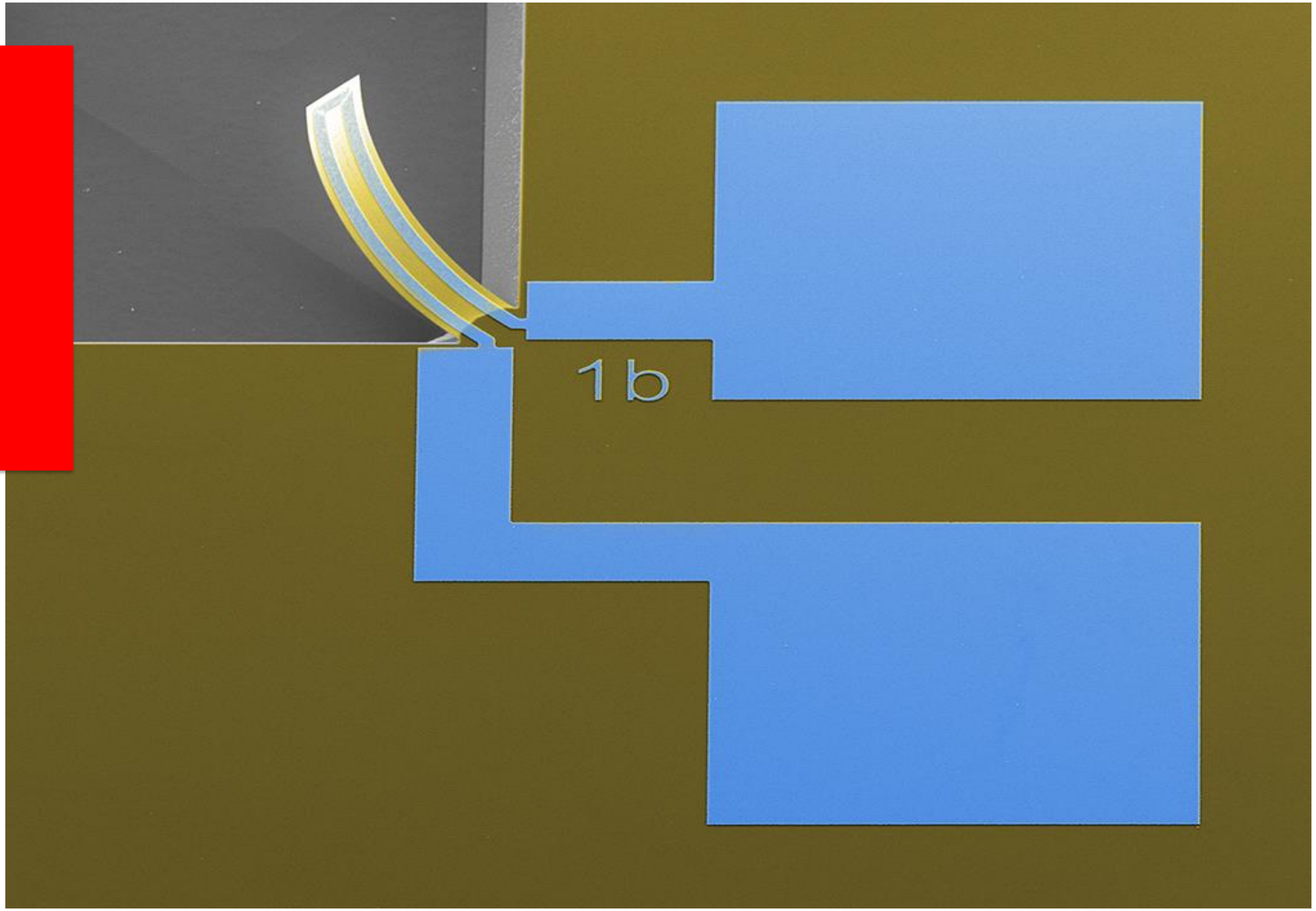
# TP A
# Thermal microactuator




**MICRO-501 MEMS practicals I**
**MEMS Actuator Practicals**

Fall semester - 2024

1st session A1

# Physical principles of a bi-morph

- Bi-morph
- Thermal expansion induces bending
- Static and dynamic behavior

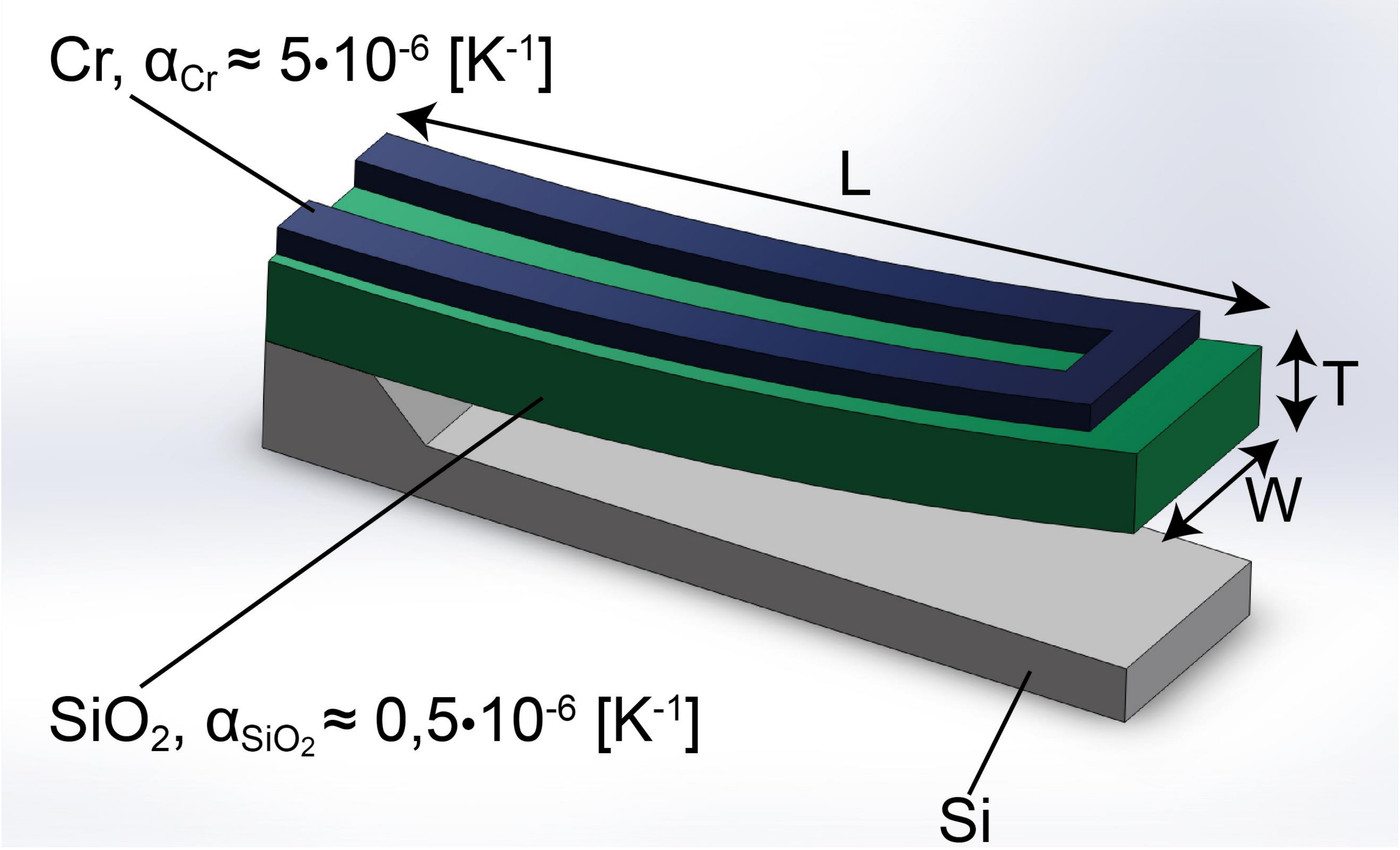

σ: strain [Pa]
E: Young's modulus [N/m$^2$]
α: thermal expansion coefficient [K $^{-1}$]
ΔT: temperature difference [K]

r: radius of curvature
t: thickness [m]
β: constant, f(t, E)

$$\boxed{\frac{1}{r} = \beta \cdot \Delta\alpha \cdot \Delta T}$$

# Scaling bi-morph to the micrometer

- Thin films (SiO2 & Cr)
- Applying voltage to Cr wire
- Joule heating
- Thermal expansion
- Bending the cantilever




k: spring constant [N/m]
E: Young's modulus [$N/m^2$]
I: area moment of inertia [$m^4$]
L: length of the beam [m]
$\omega_{res}$: resonant angular frequency [s-1]
$m_{eff}$: beam effective mass [kg]

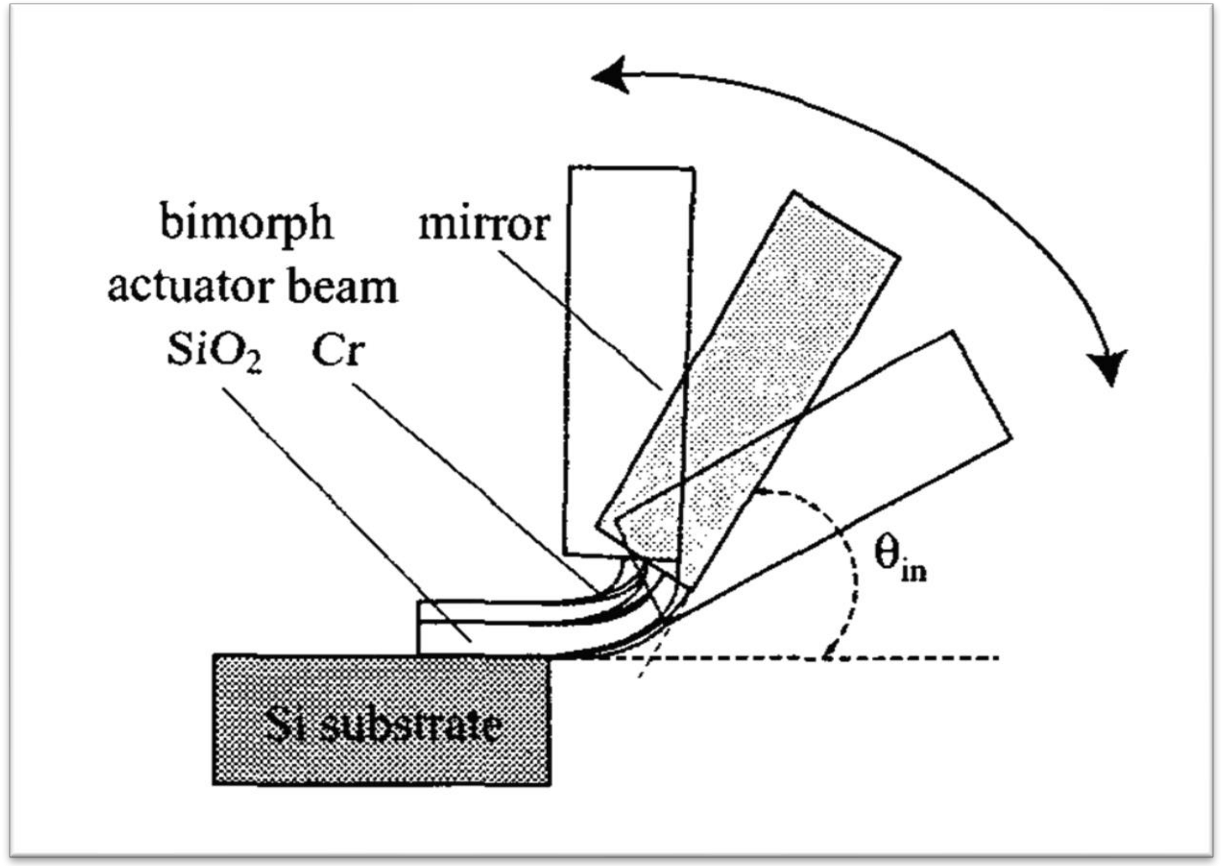
$$k = \frac{3EI}{L^3} \qquad \omega_{res} = \sqrt{\frac{k}{m_{eff}}}$$

# Applications of bi-morph micro cantilevers

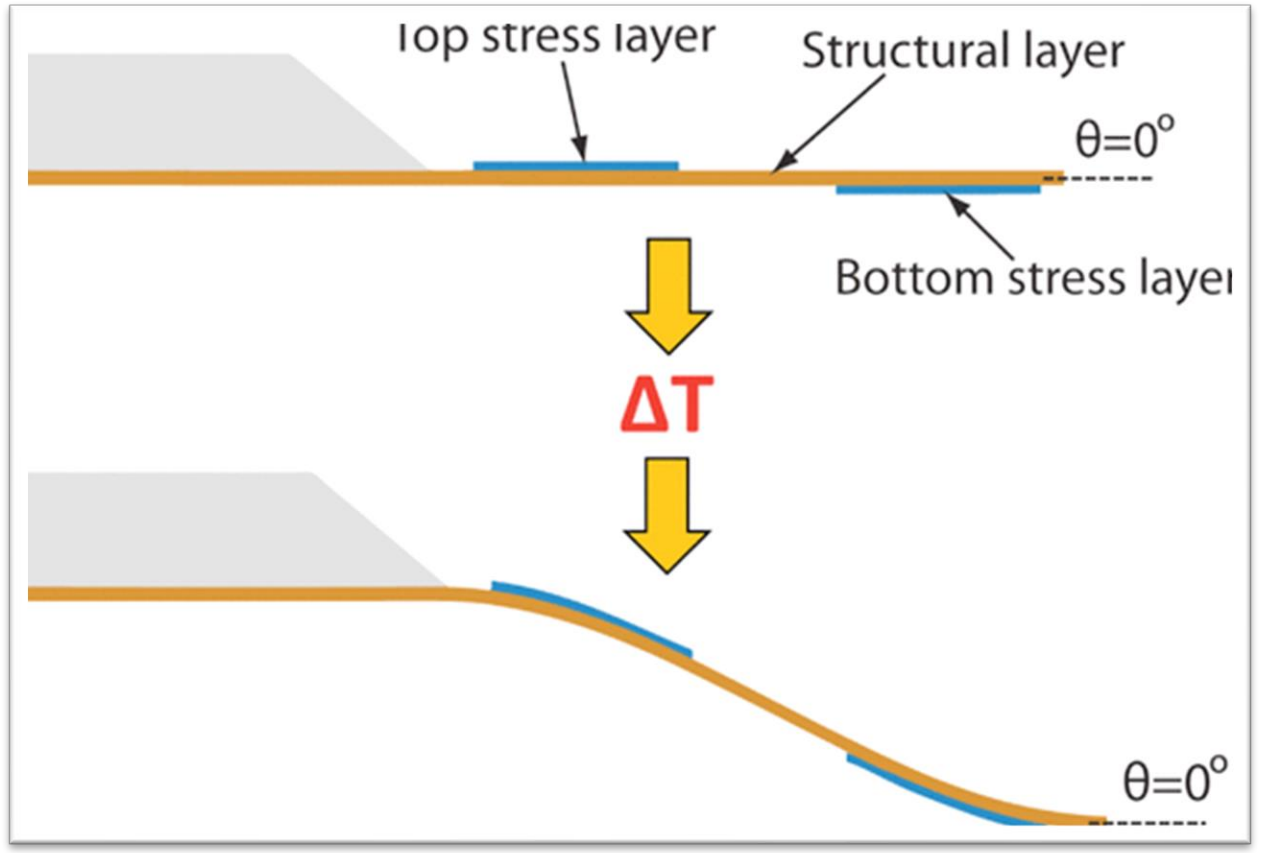
- Optical beam manipulation
  - Switching and scanning of light
  - Laser beam printers, barcode readers, optical sensors

- AFM cantilever actuation
  - Positioning and scanning of cantilever
  - Tip height and contact force control

- Pros: high amplitude and force ratio
- Cons: power dissipation and dynamic range




PhD
S. Schweizer
EPFL (2001)




PhD
J. Henriksson
EPFL (2015)

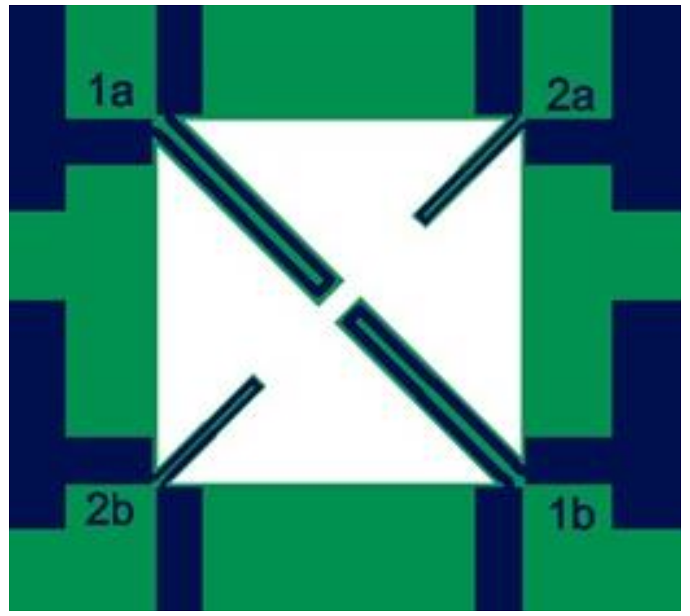
# A1 Session

- **1st A1 session on Monday 23.09.2024 from 8h15-10h :**
  - Answer the questions 1-5 available in the instructions on Moodle :
    - TP-A-Instructions-Fall2024-V1.pdf
  - Consult the references on Moodle, they can also help you.

- By **Thursday 26.09.2024 13h**
  - Verify if you can run Klayout your computer
  - Submit a short report with your answers to the questions 1-5 to berke.erbas@epfl.ch

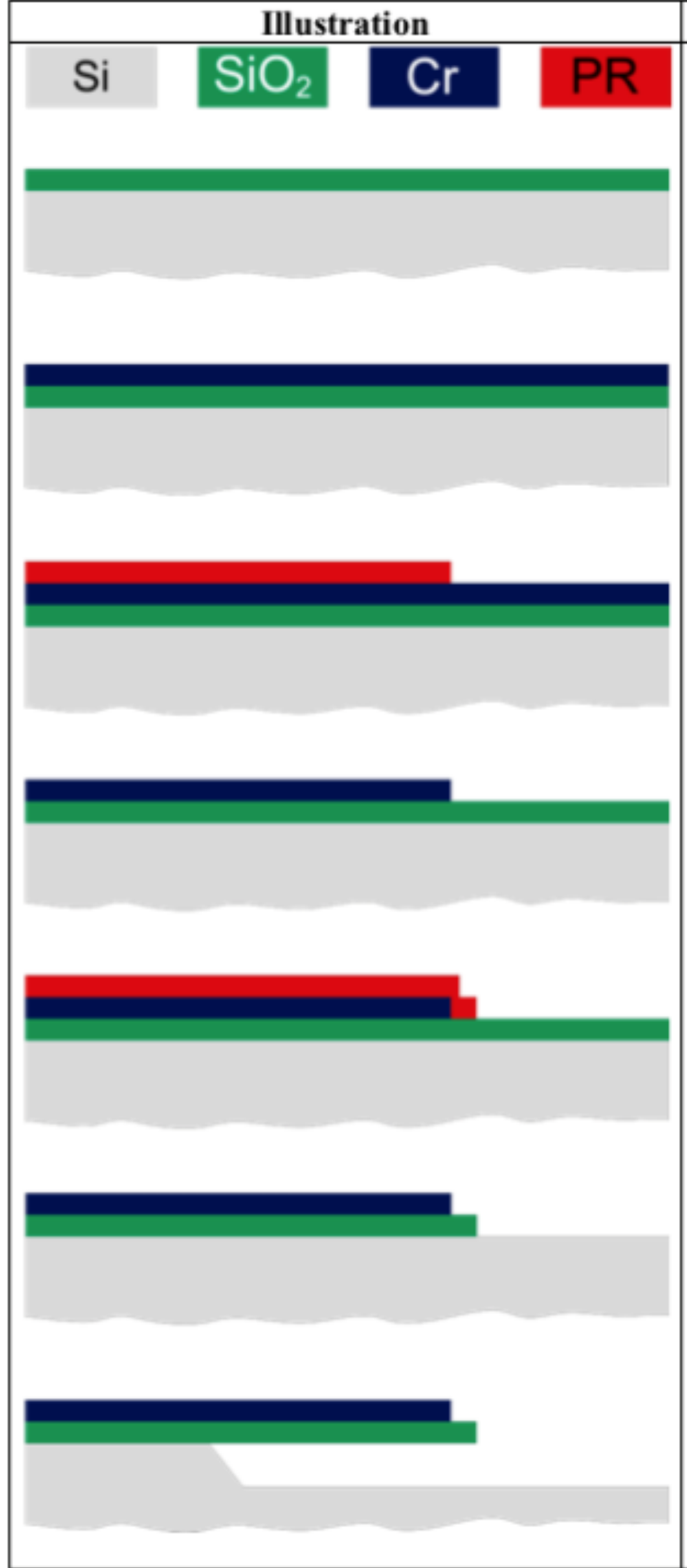
- **2nd A1 session on Monday 30.09.2024 from 8h15-10h**:
  - Feedback on your answers provided during the lesson
  - Design of the cantilevers using Klayout, including a funcy design!
  - Simulation of the KOH etching with ACES

- By **Thursday 03.10.2024 8h**, submit your ACES simulation results and design file .gds to berke.erbas@epfl.ch



# A2-A3 Sessions

- **Fabrication of the cantilevers in the clean room**
  - Refer to the schedule of the class to know your date/TA
  - Each group does session A2 or A3 (4h each)
  - Read the **safety instructions** to work in the clean room before your session
    - Safety and Behavior in the Cleanroom_15BM+1 TP's.pptx
  - The **instructions** file explains the full process
    - TP-A-Instructions-Fall2024-V1.pdf
    - There are questions for you to answer during the clean room part Q1-Q15 for A2 groups or Q16-Q30 for A3 groups
  - The **process flow** file reports the global steps to be done
    - 501-TP-process-flow.pdf
  - The **runcard** file contains the machines and parameters used
    - TP_A Runcard_Fall2024_v1.pdf




**Description**

**1 Wafer preparation & wet oxidation**
* RCA cleaning
* Wet oxidation (1.5 µm)

**2 Metal deposition by PVD**
* Cr evaporation/sputtering (500 nm)
* E-beam source

**3 Photolithography to pattern heaters (A2)**
* Spin coating
* UV exposure
* Development

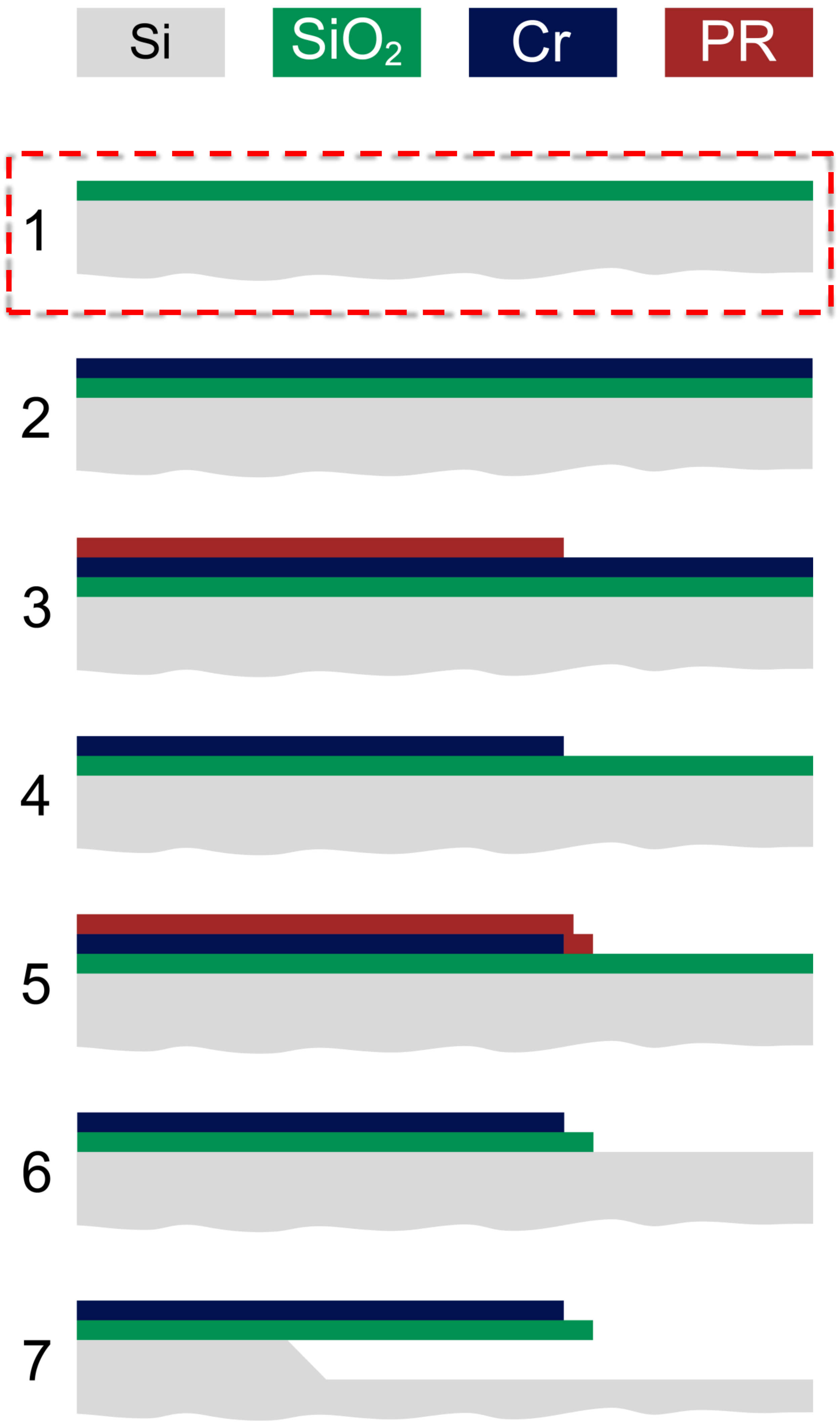
**4 Cr etch (A2)**
* Cr wet etching
* Resist stripping
* Track resistance measurement

**5 Photolithography to pattern beams (A3)**
* Spin coating
* UV exposure
* Development

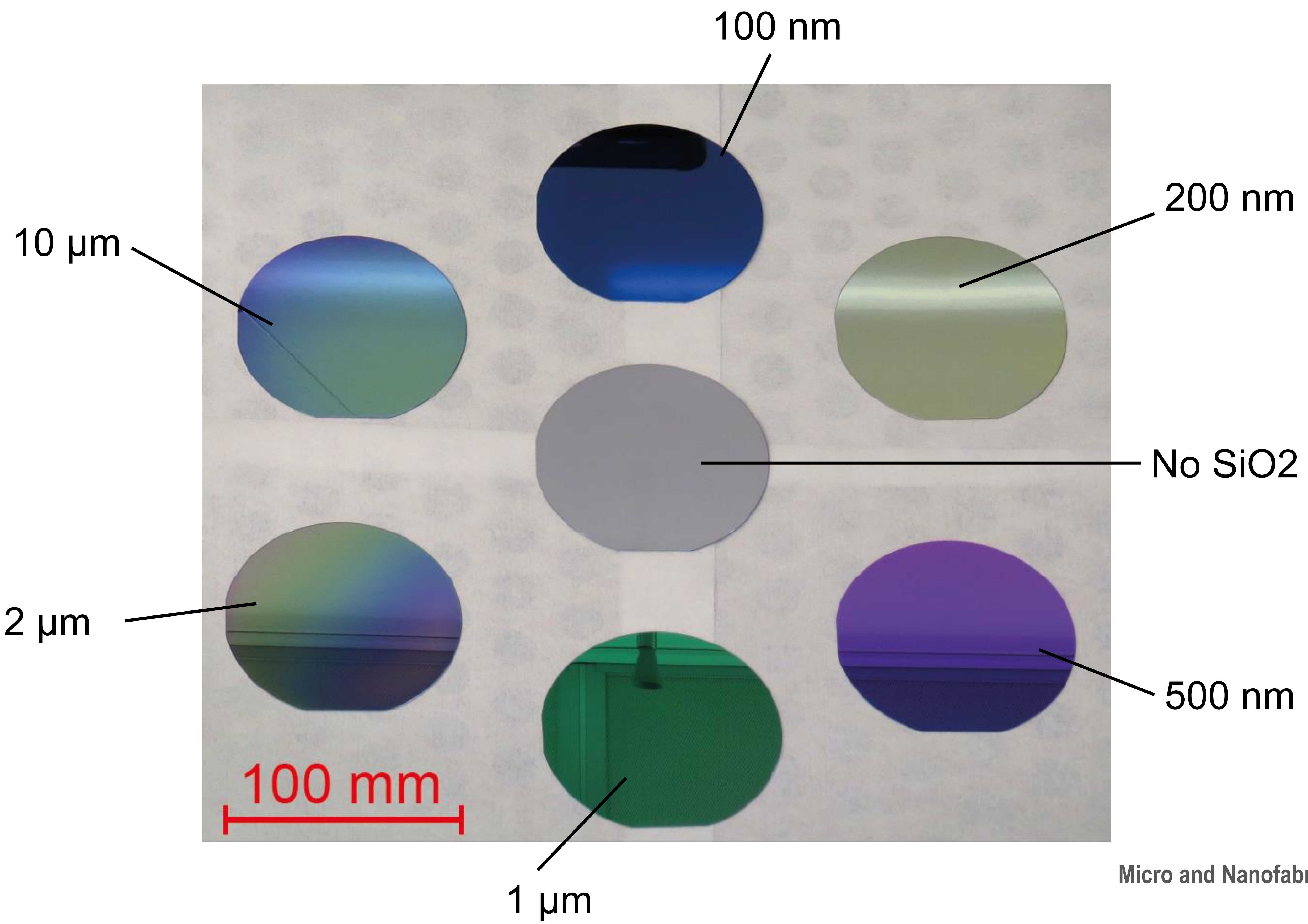
**6 $SiO_2$ etch (A3)**
* Oxide wet etching by HF (BOE)
* Resist stripping
* Cr and $SiO_2$ thickness measurement

**7 Si etch**
* Anisotropic Si etching in KOH

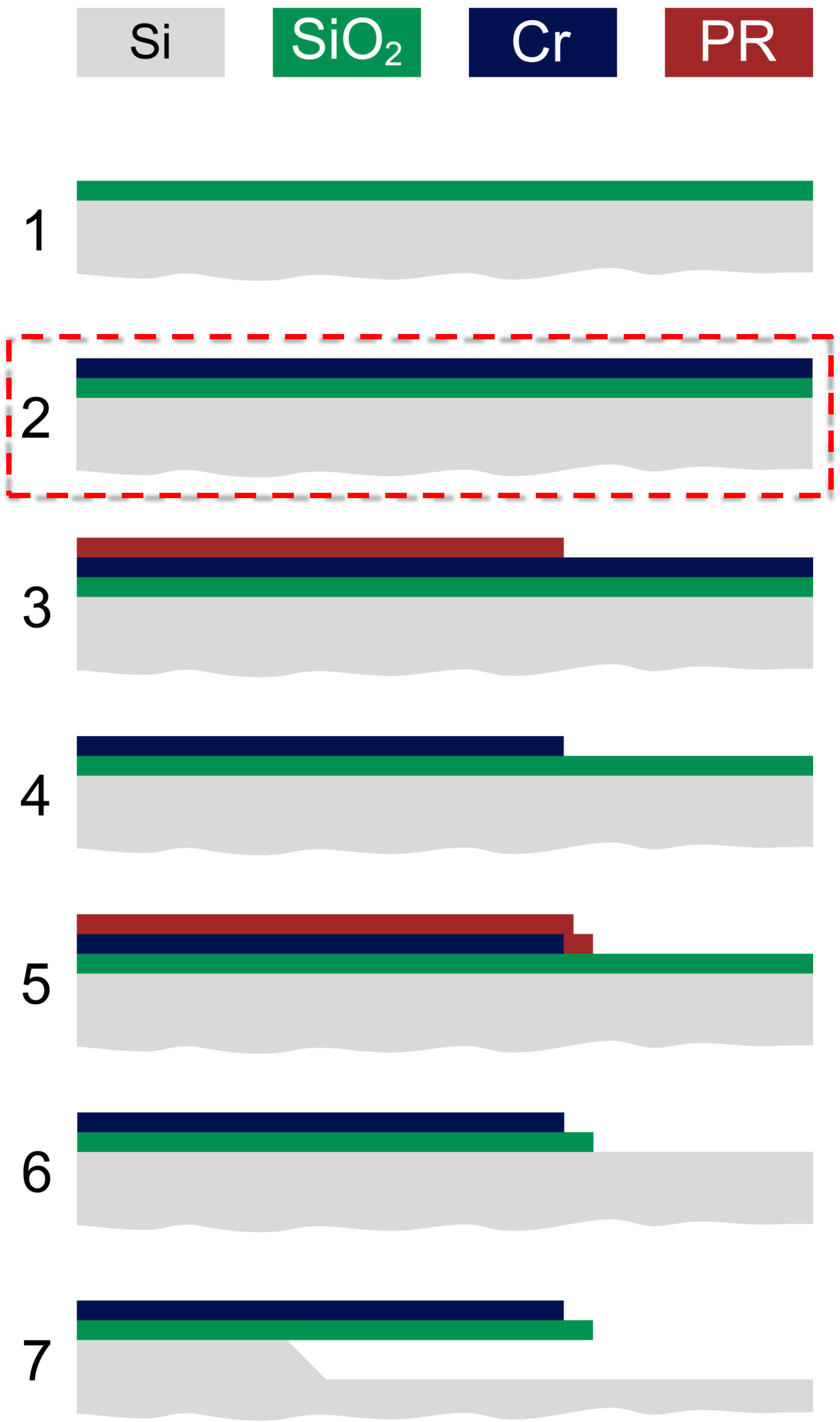
# Step 1: Wafer prep and wet oxidation



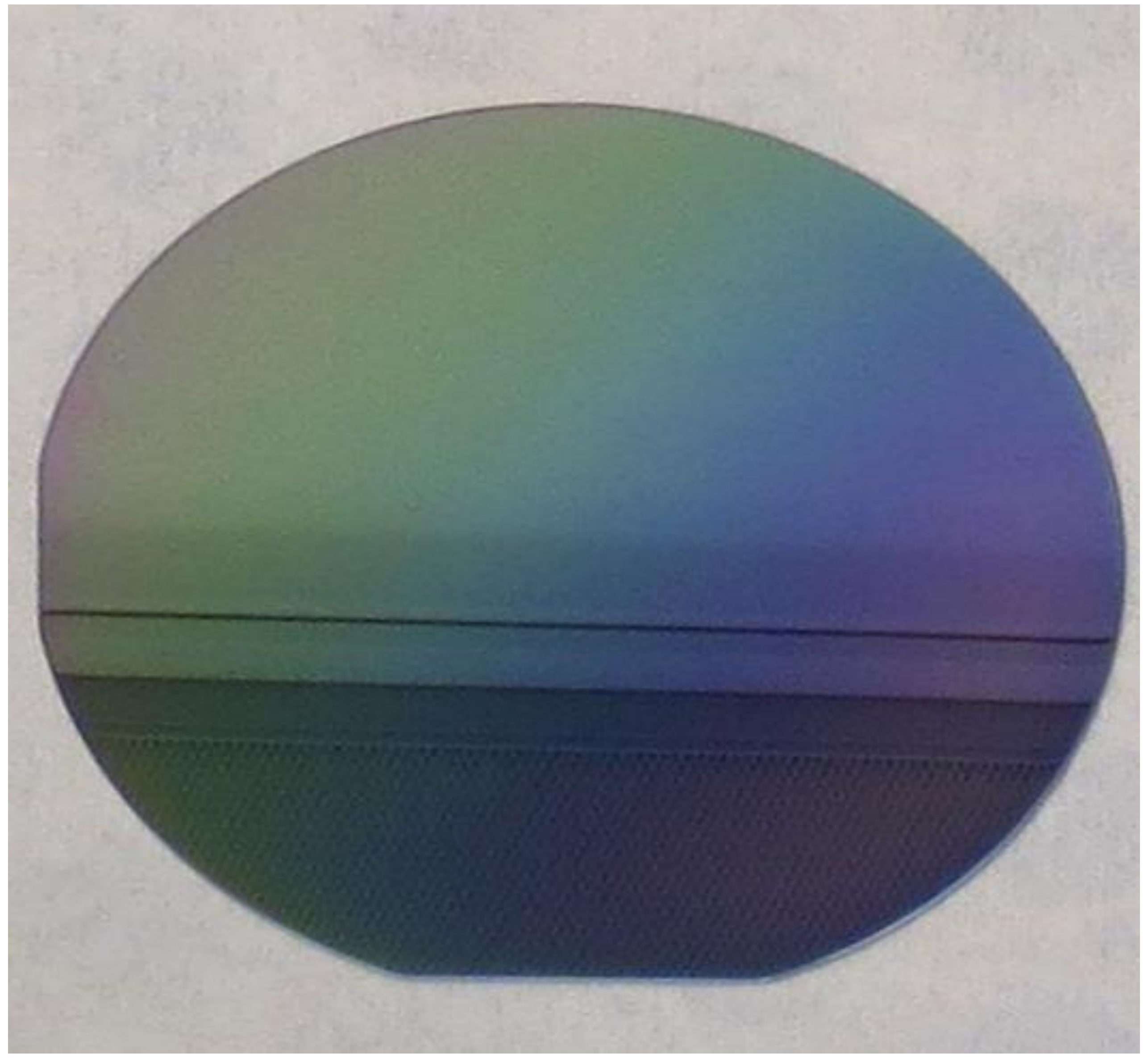

- RCA cleaning
- Wet oxidation (1100C,1.5 μm)



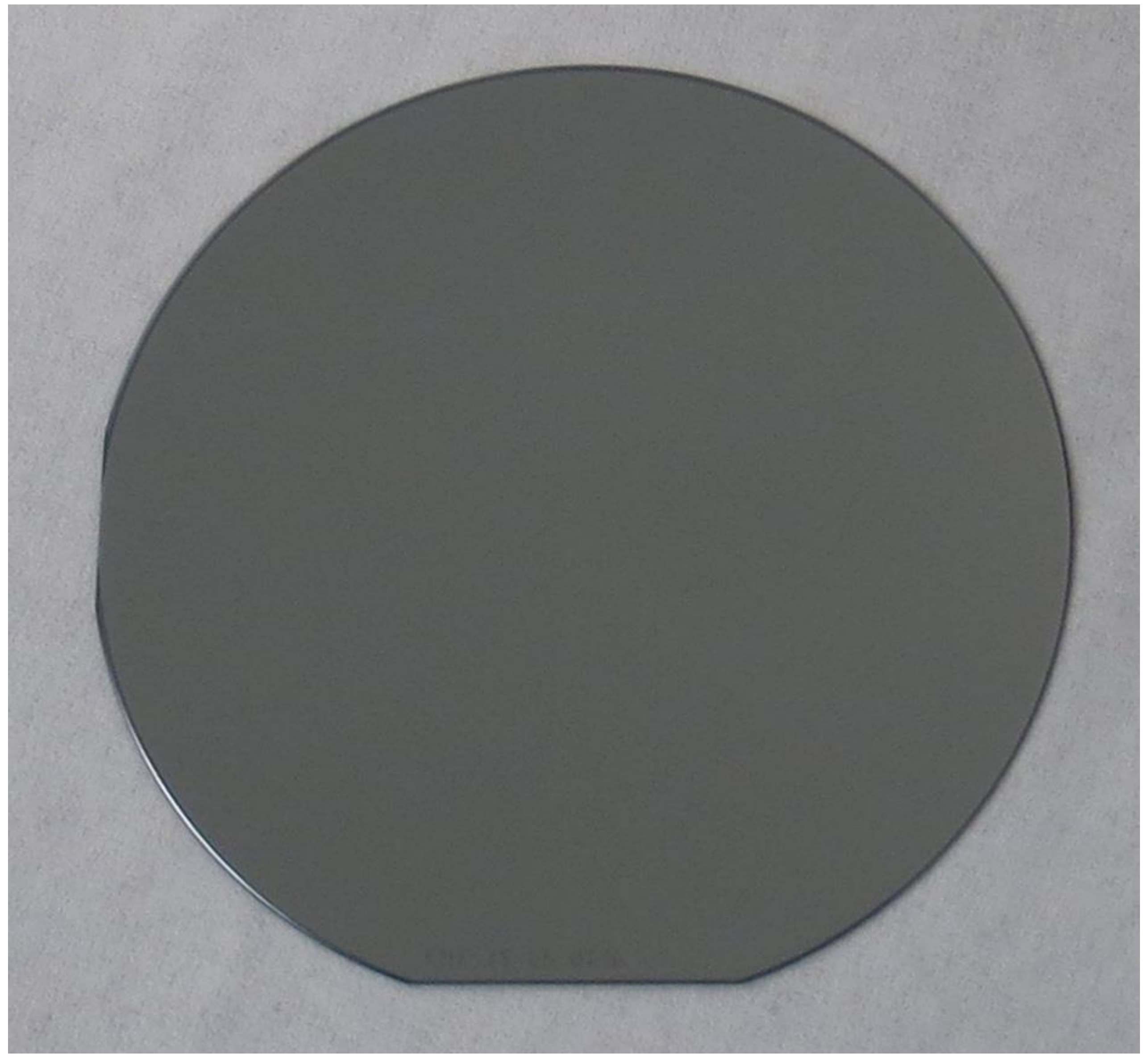
# Step 2: metal deposition by PVD




- Physical vapor deposition (high vacuum)
- Cr thickness: 500 nm
- E-beam source

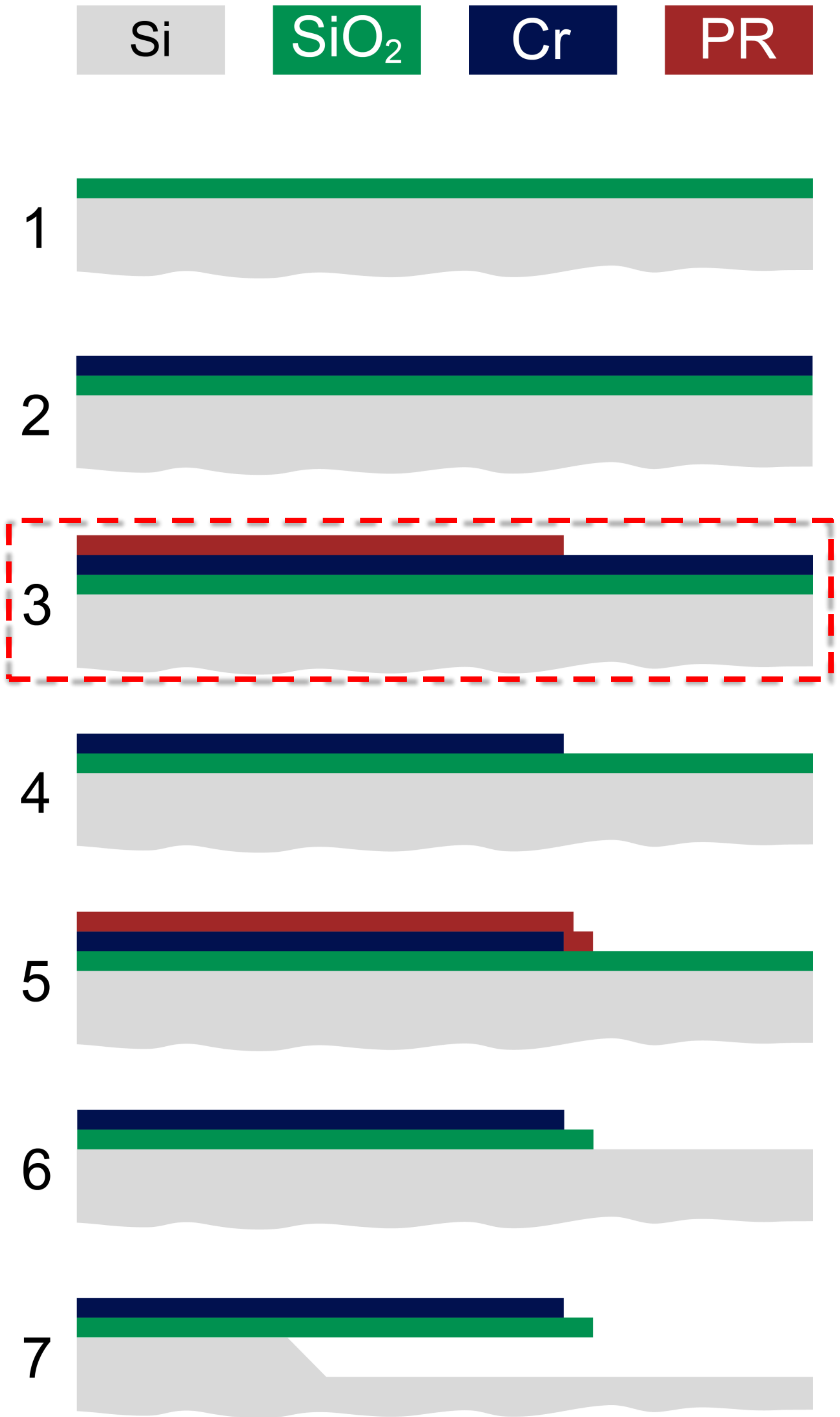


Silicon dioxide

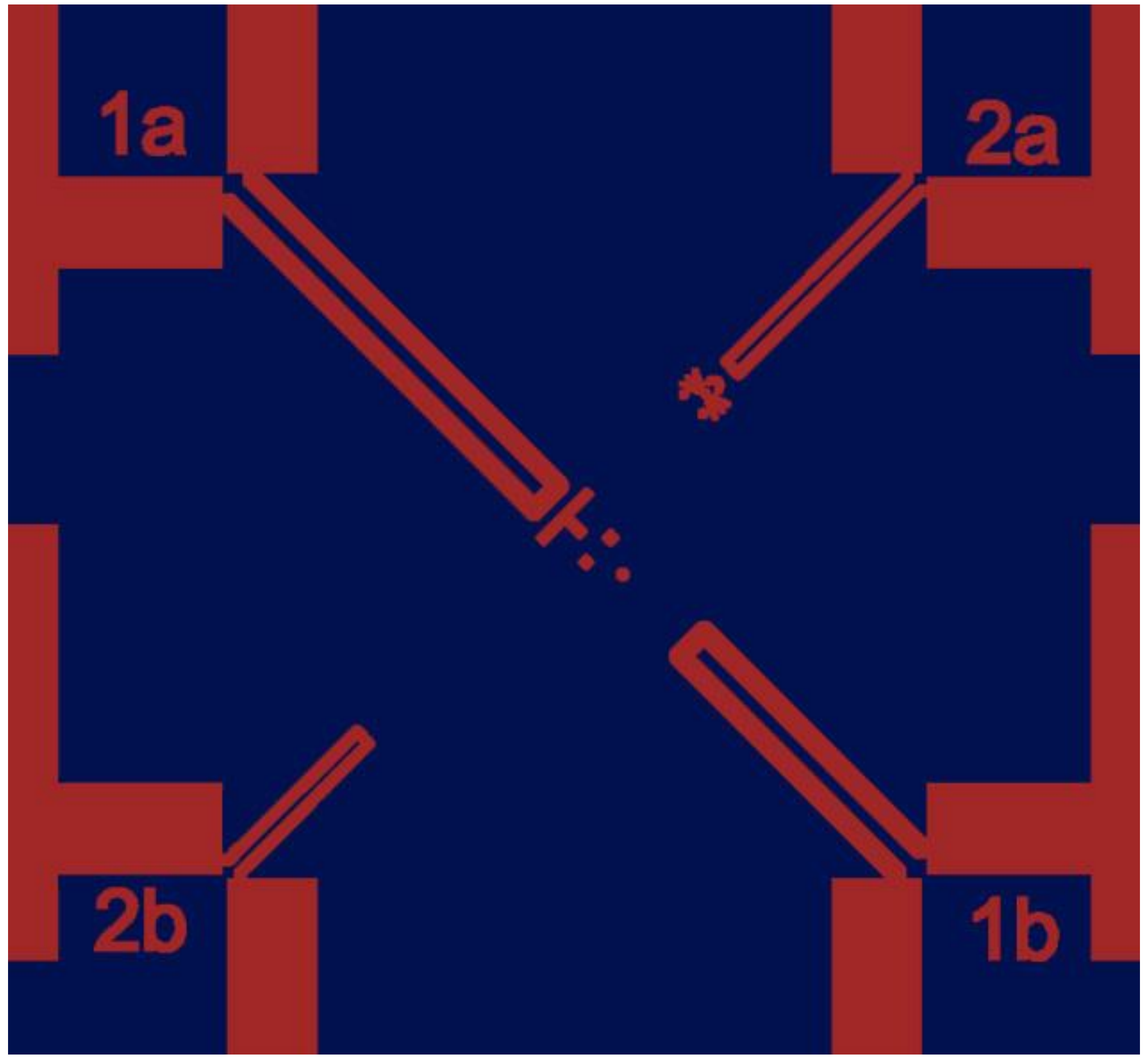


Chromium

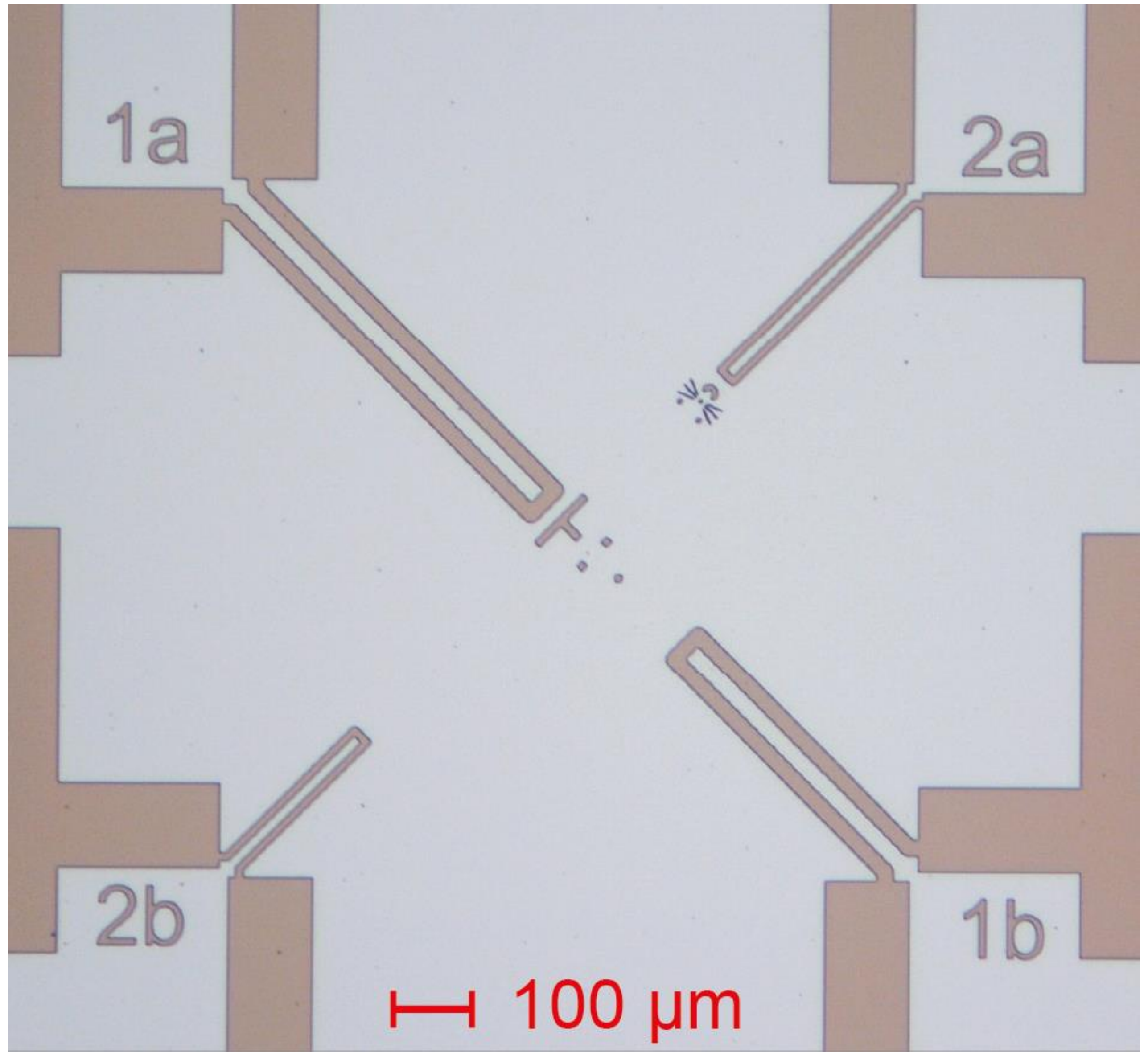
# Step 3: Photolithography to pattern the heaters




- Spin coating of photoresist
- UV exposure through mask
- Development

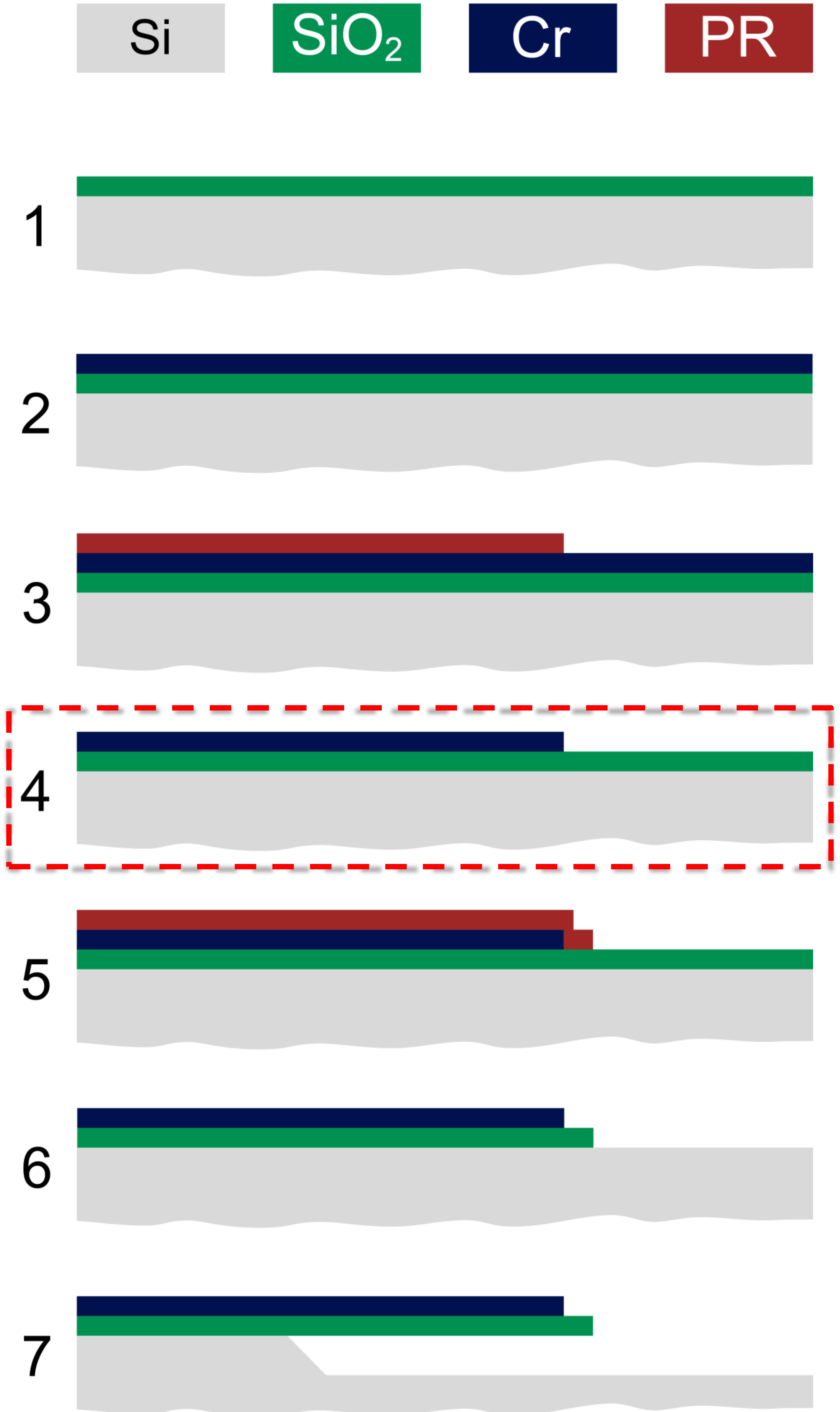


Design

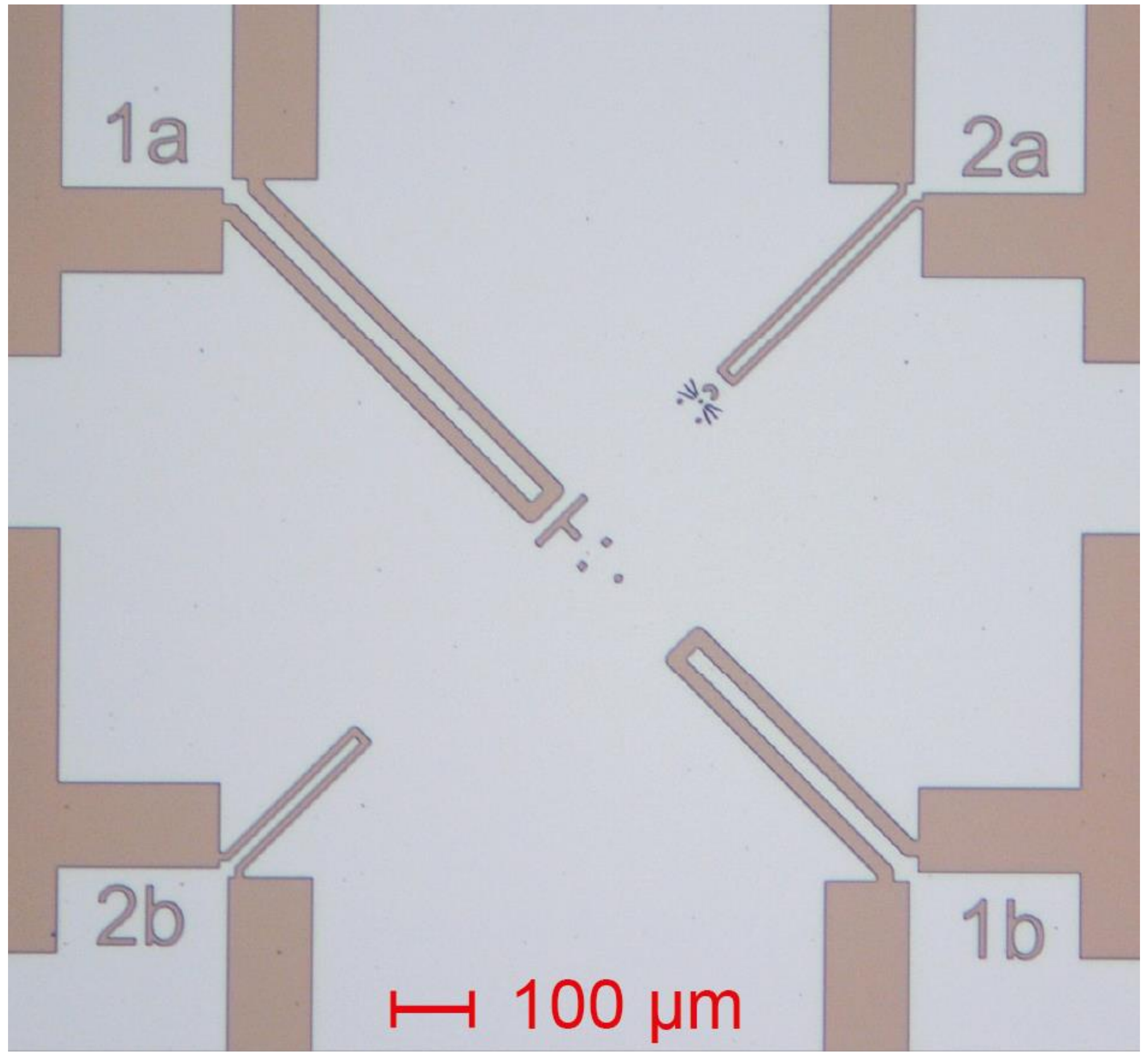


Fabricated result

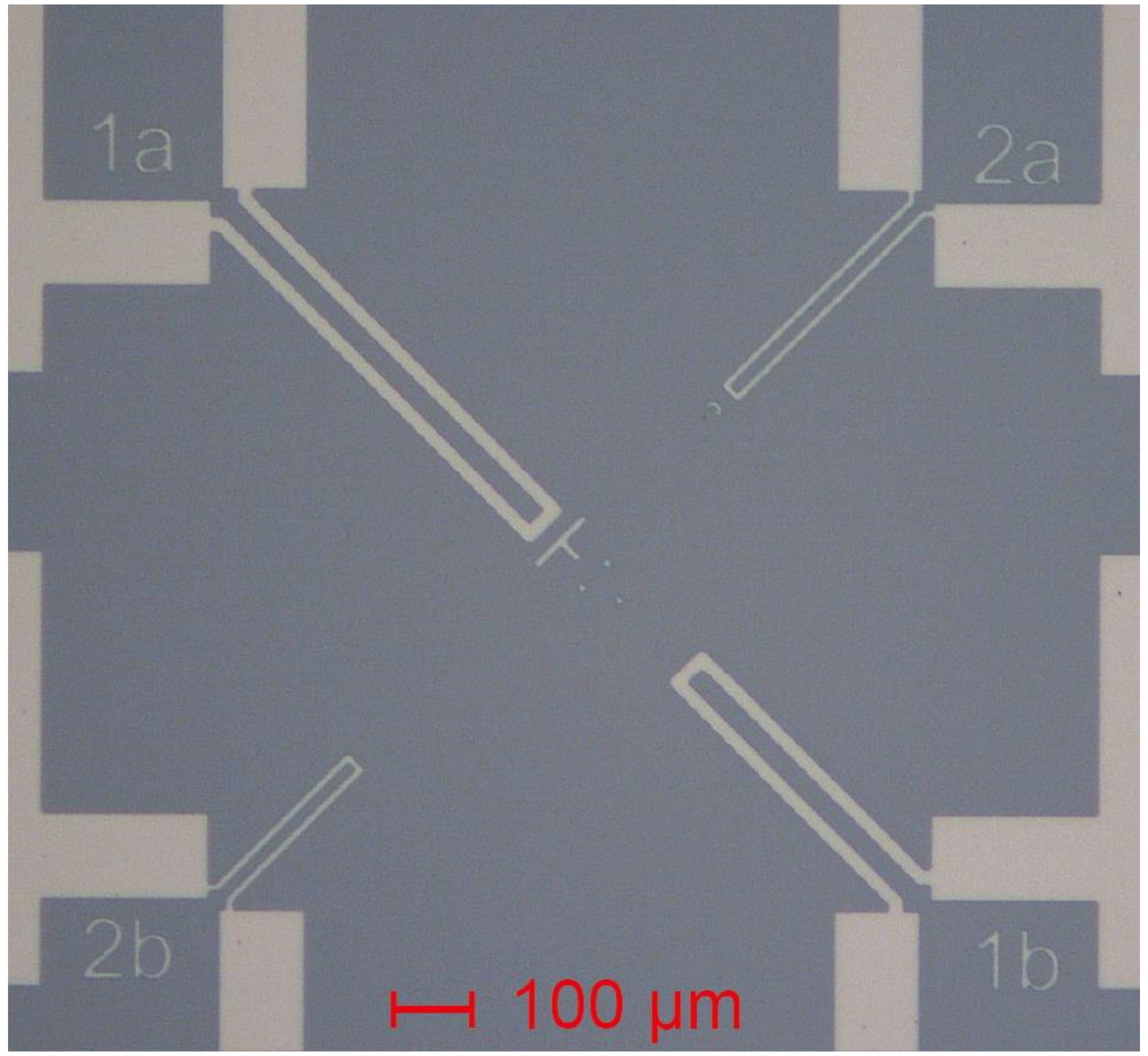
# Step 4: Chrome etch




- Cr wet etching
- Resist stripping

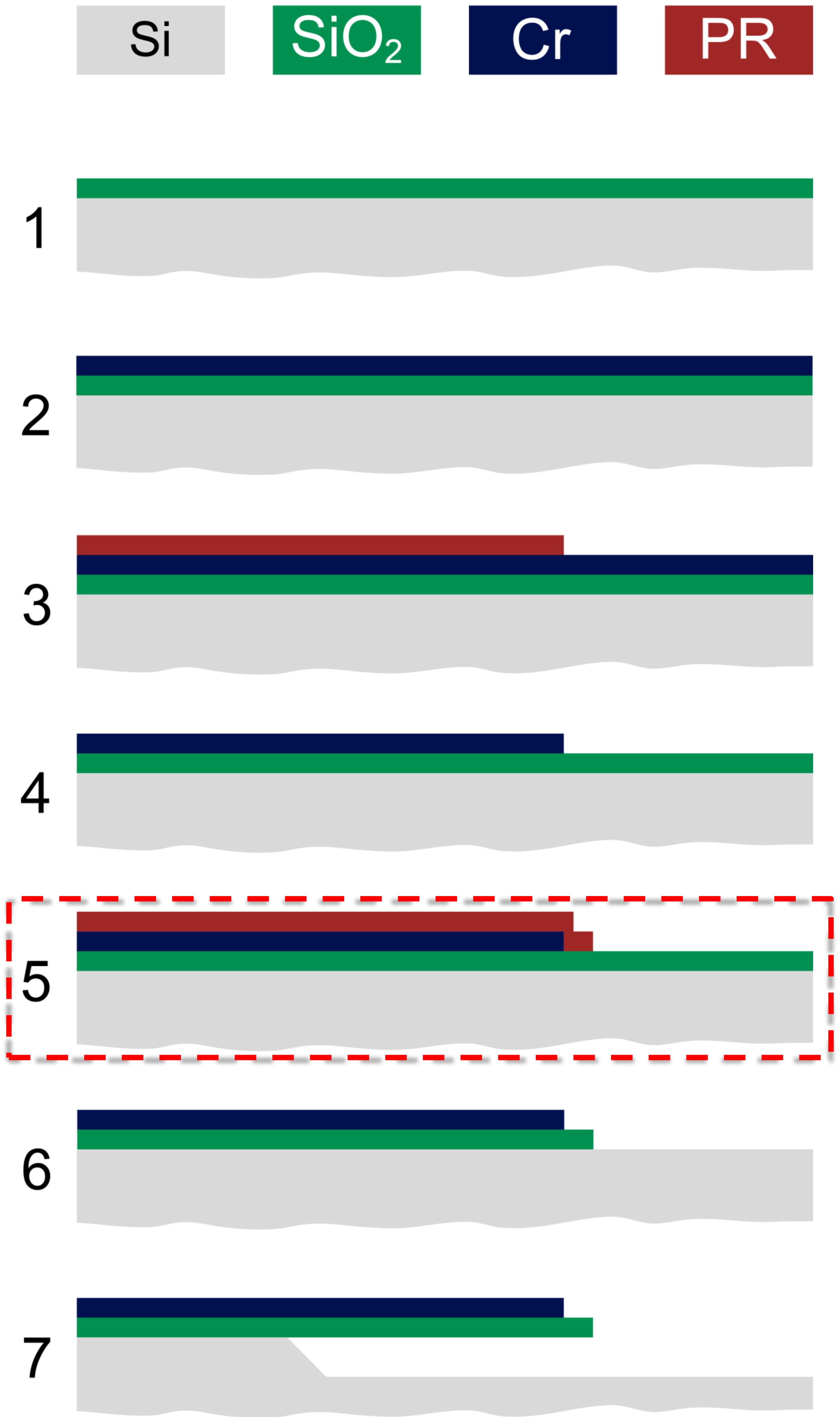




After lithography

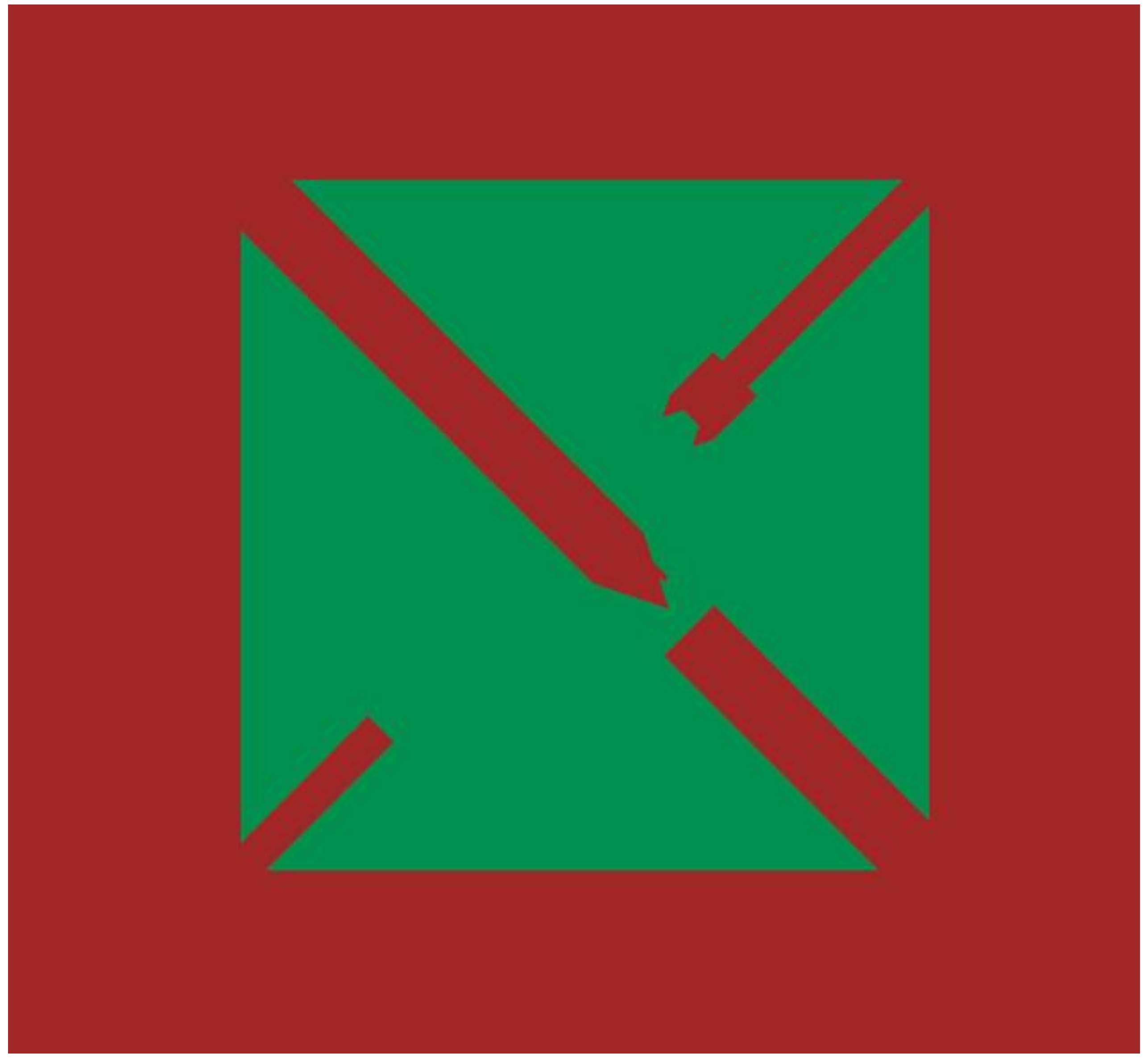



After Cr etching

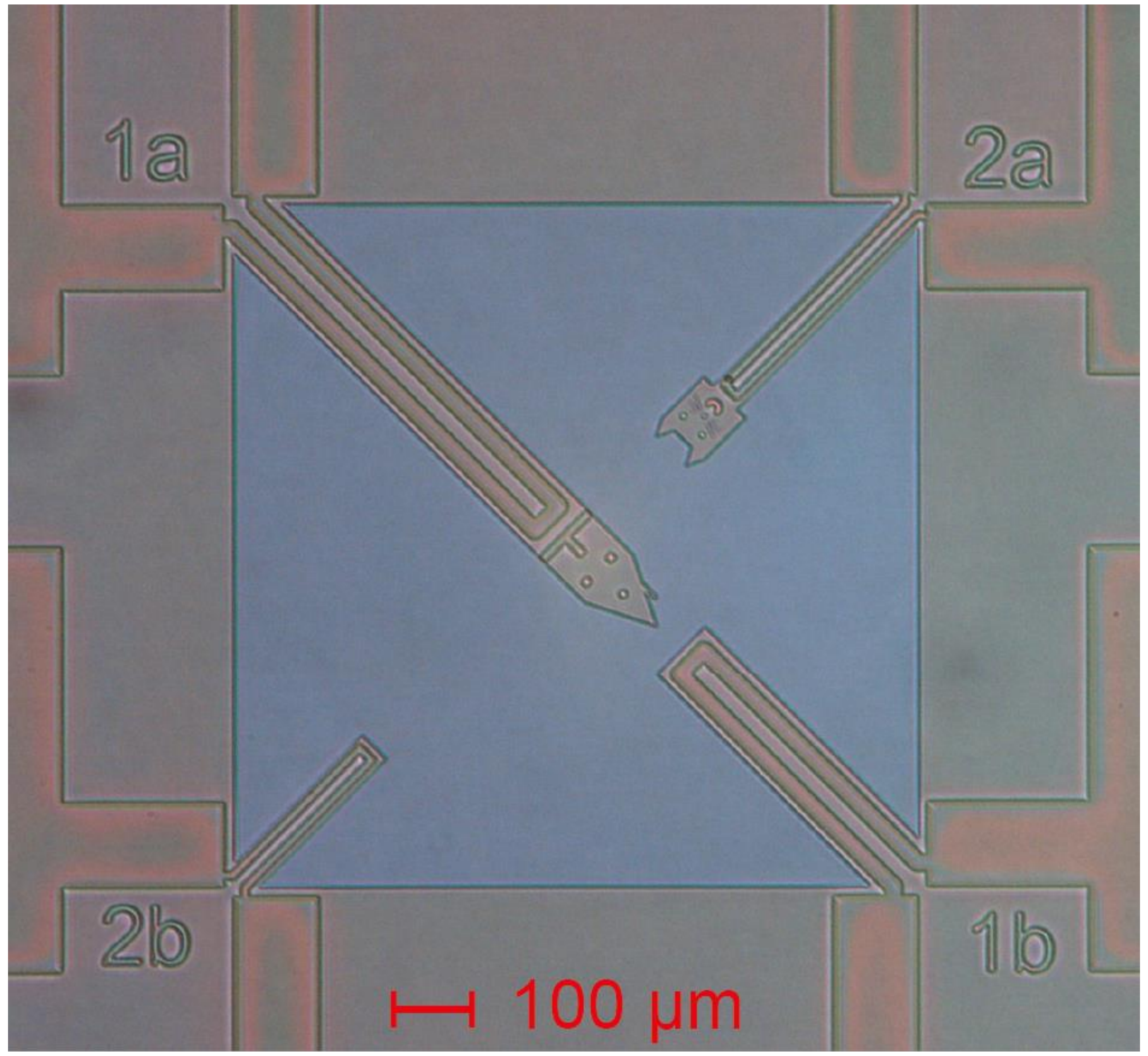
# Step 5: Photolithography to pattern the beams




- Spin coating
- UV exposure
- Development

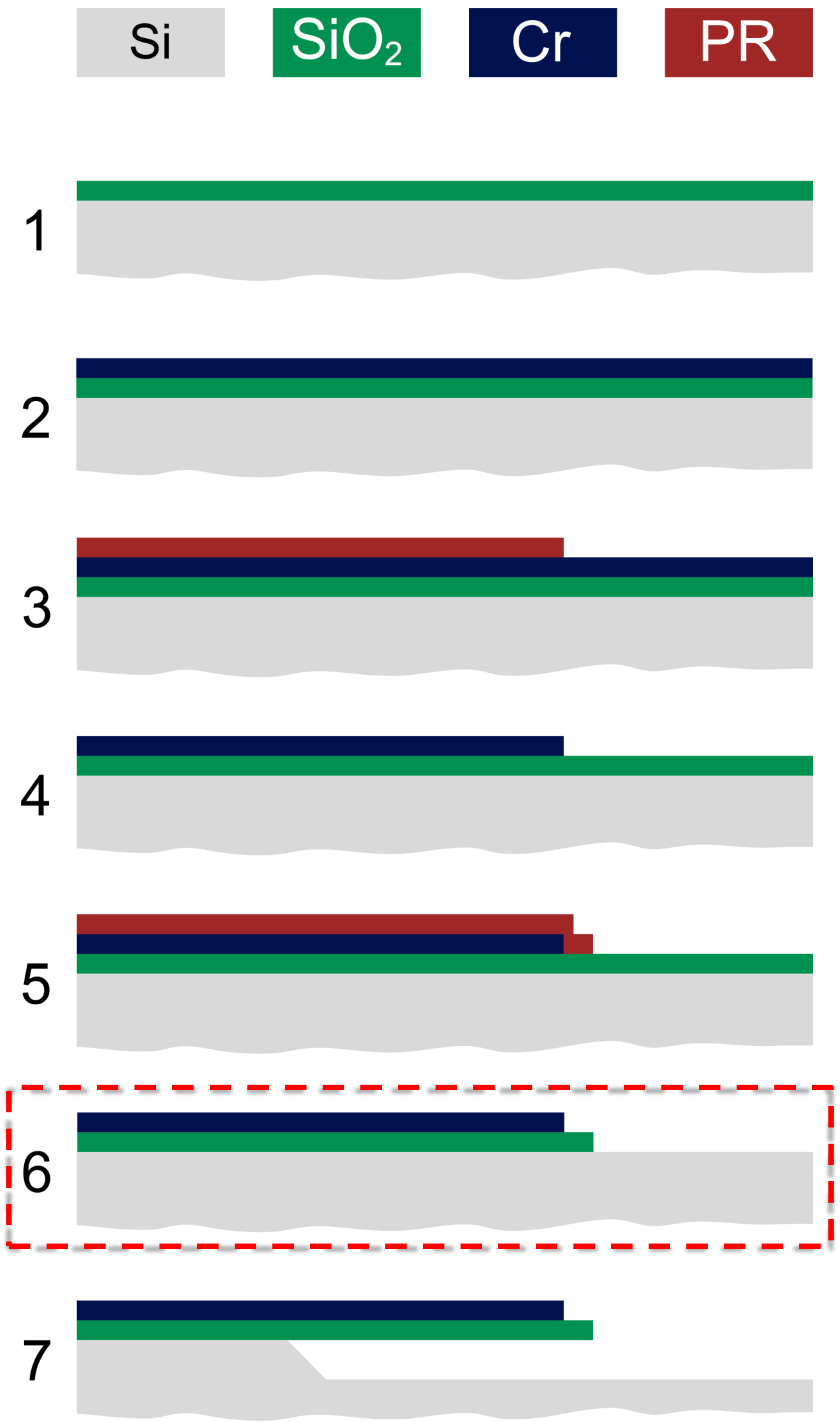


Design



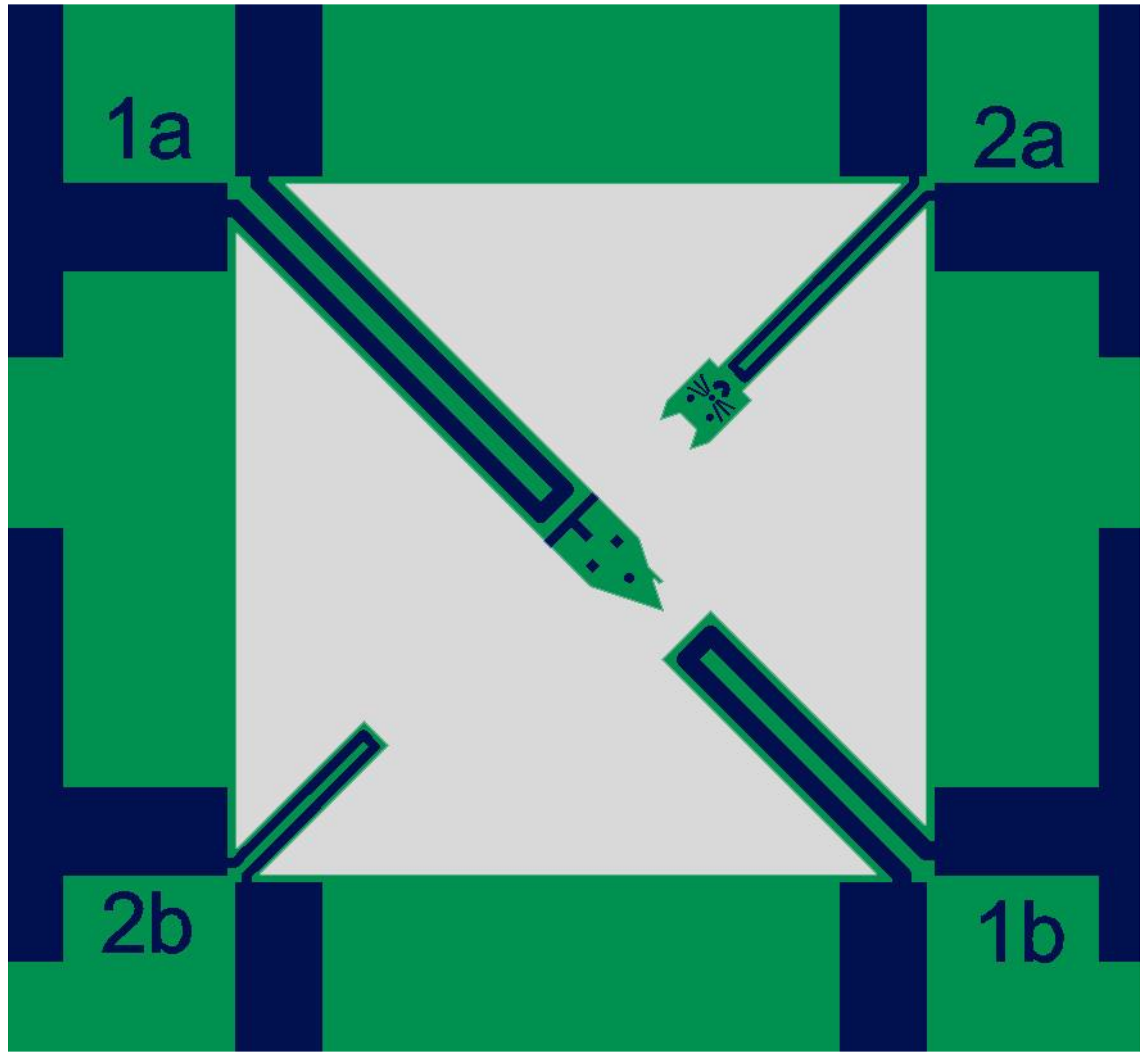

Fabricated result

# Step 6: SiO2 etch

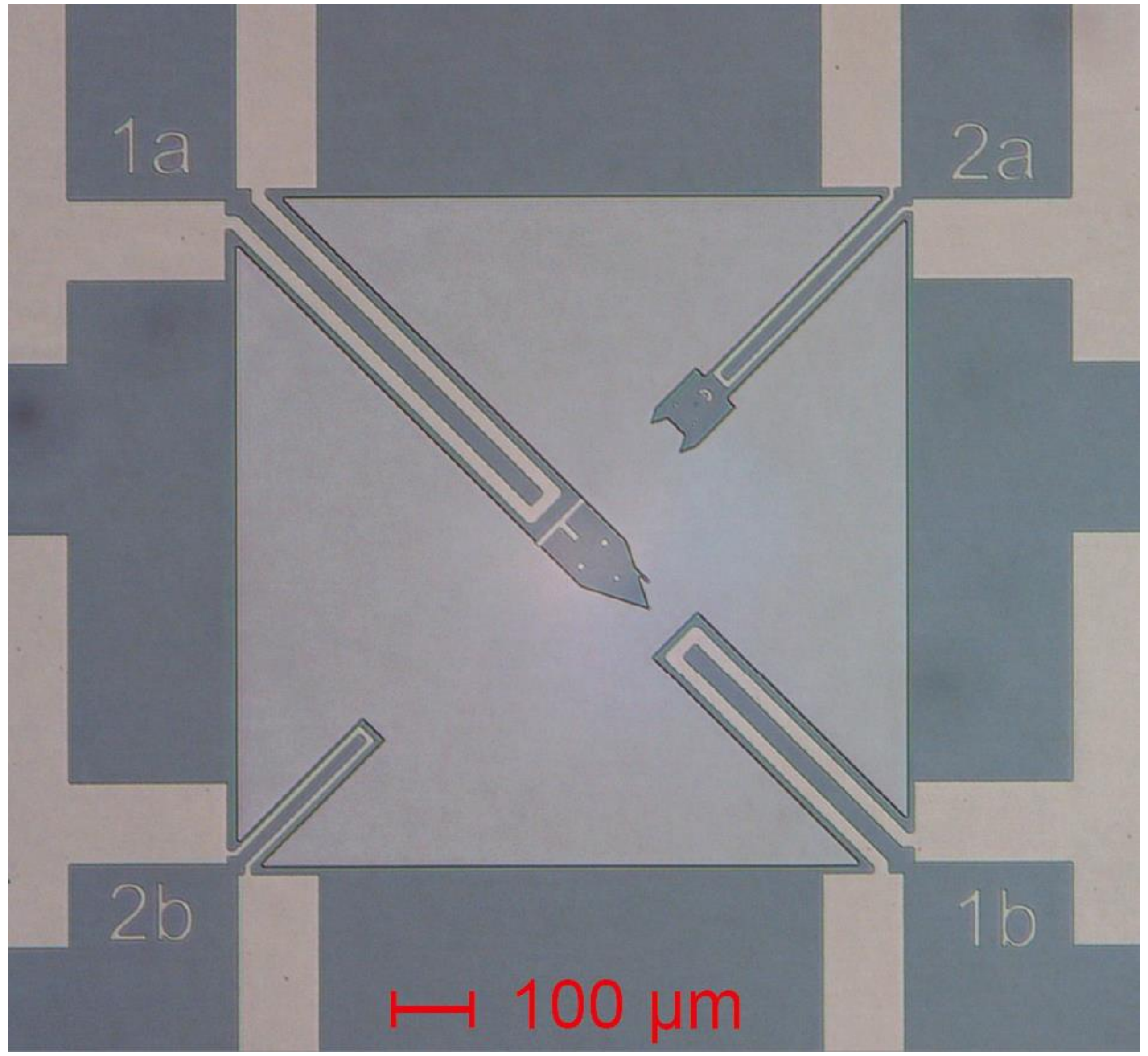



- Oxide wet etching by HF
- Resist stripping

Careful !
HF is dangerous !

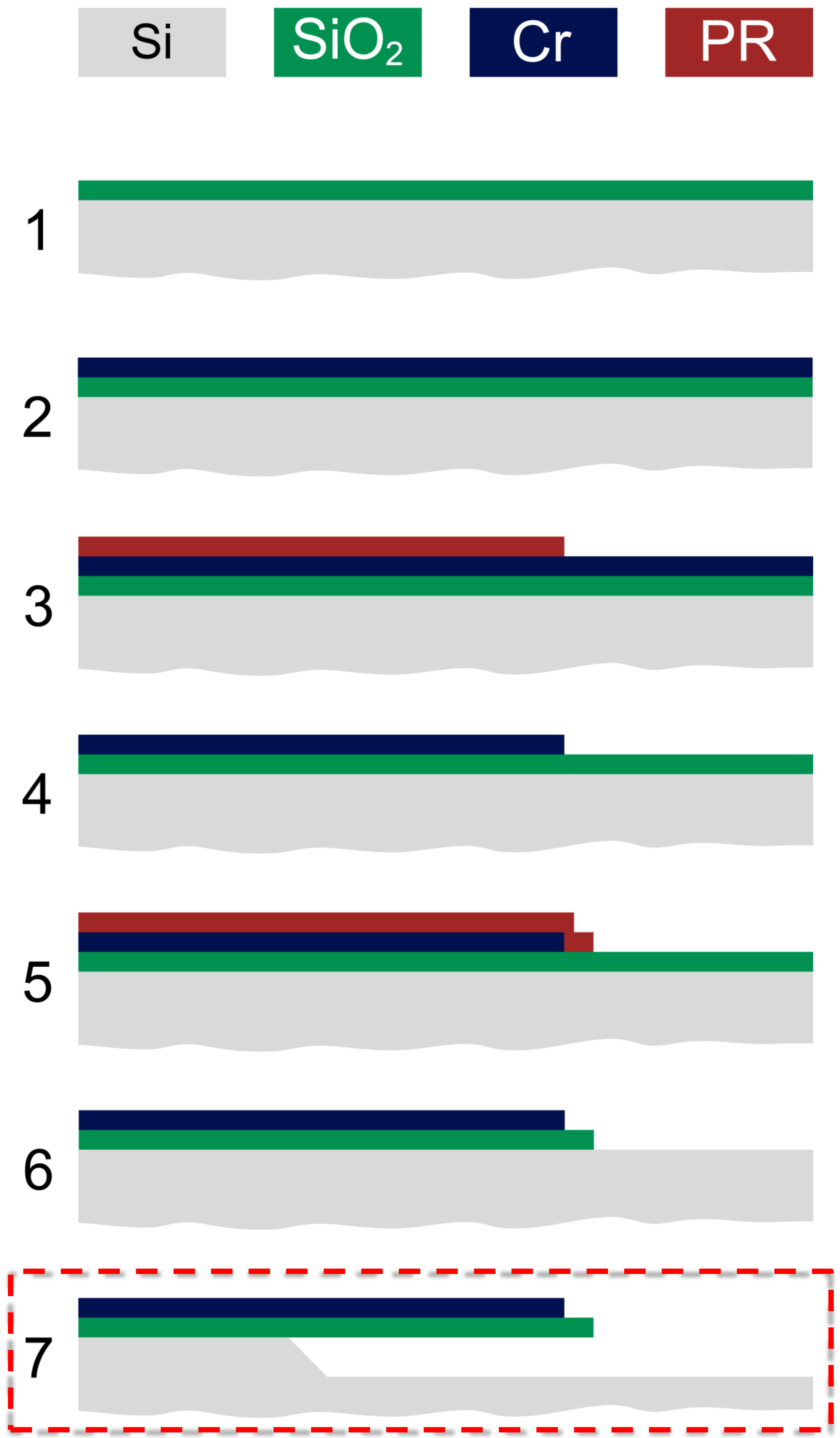



Design

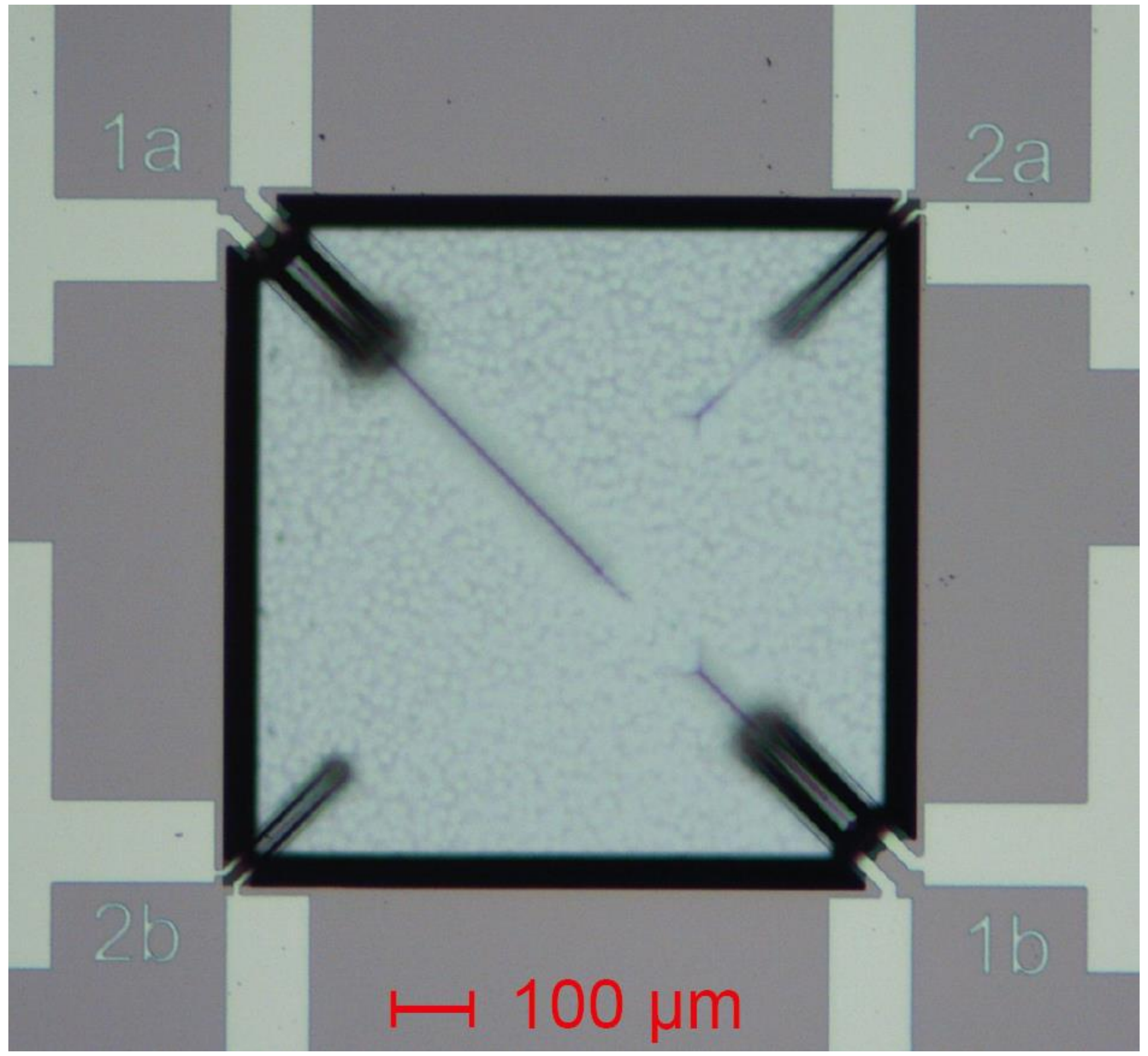



Fabricated result

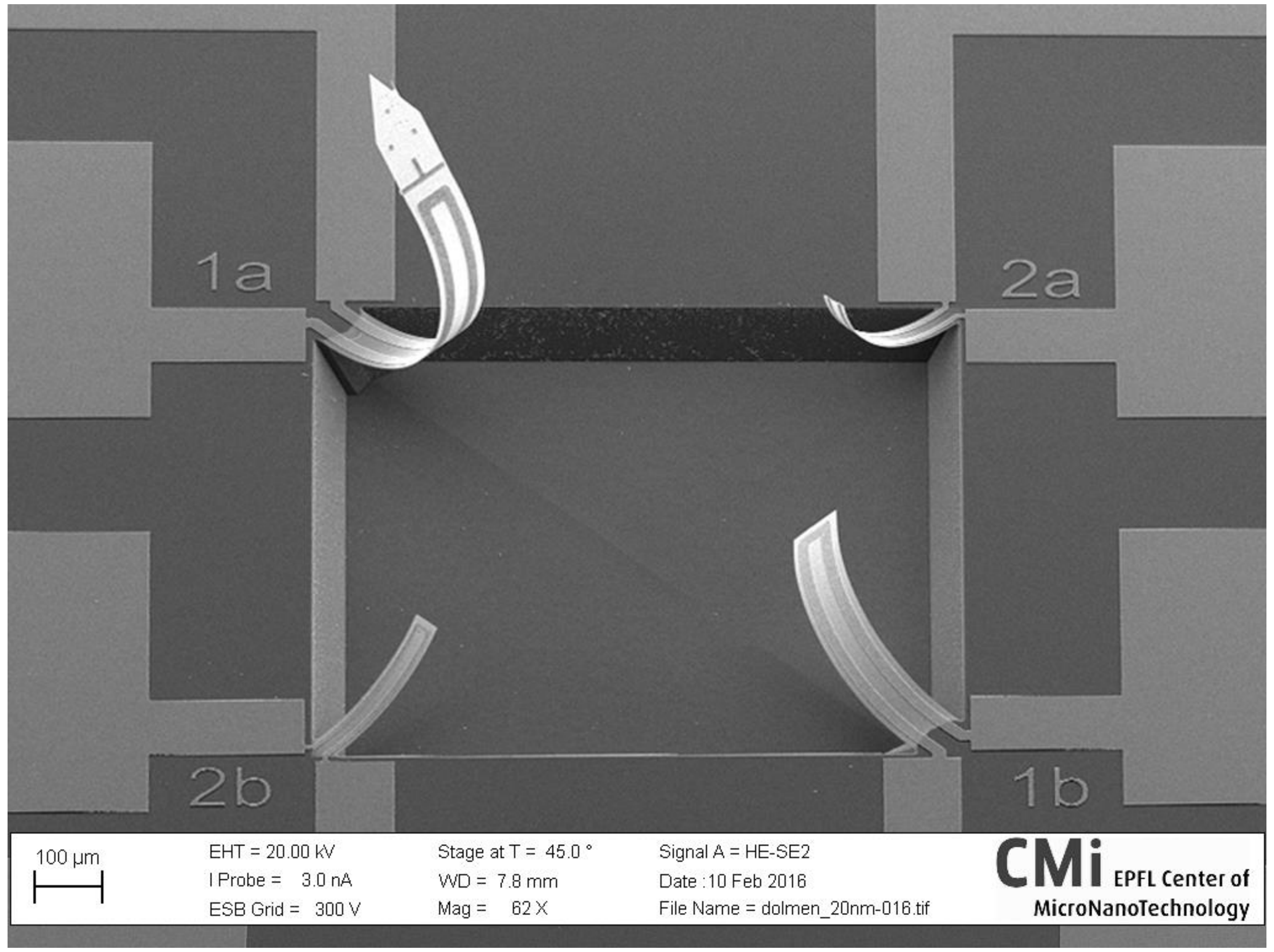
# Step 7: Silicon etch




- Anisotropic Si etching in KOH
- Beams are released

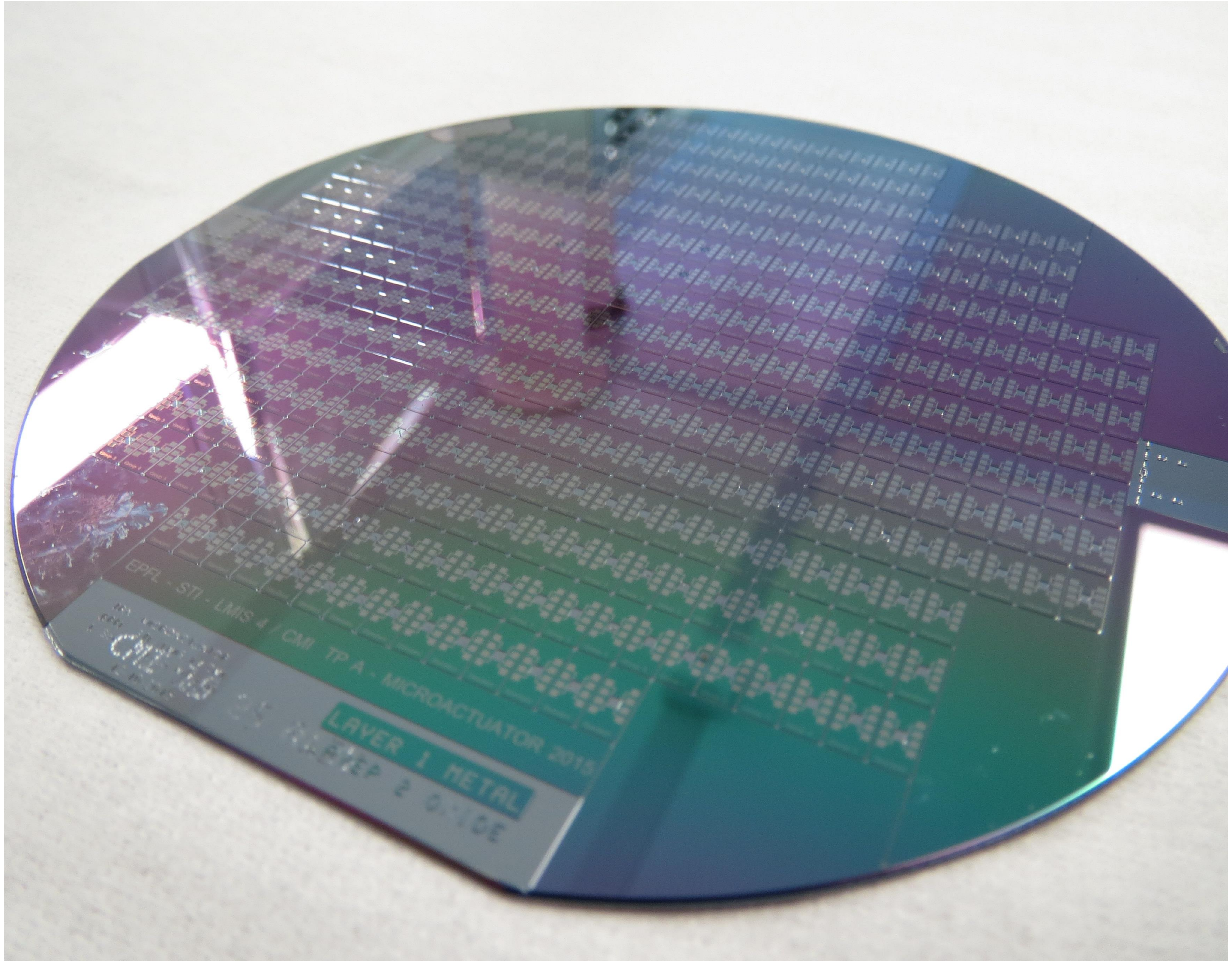


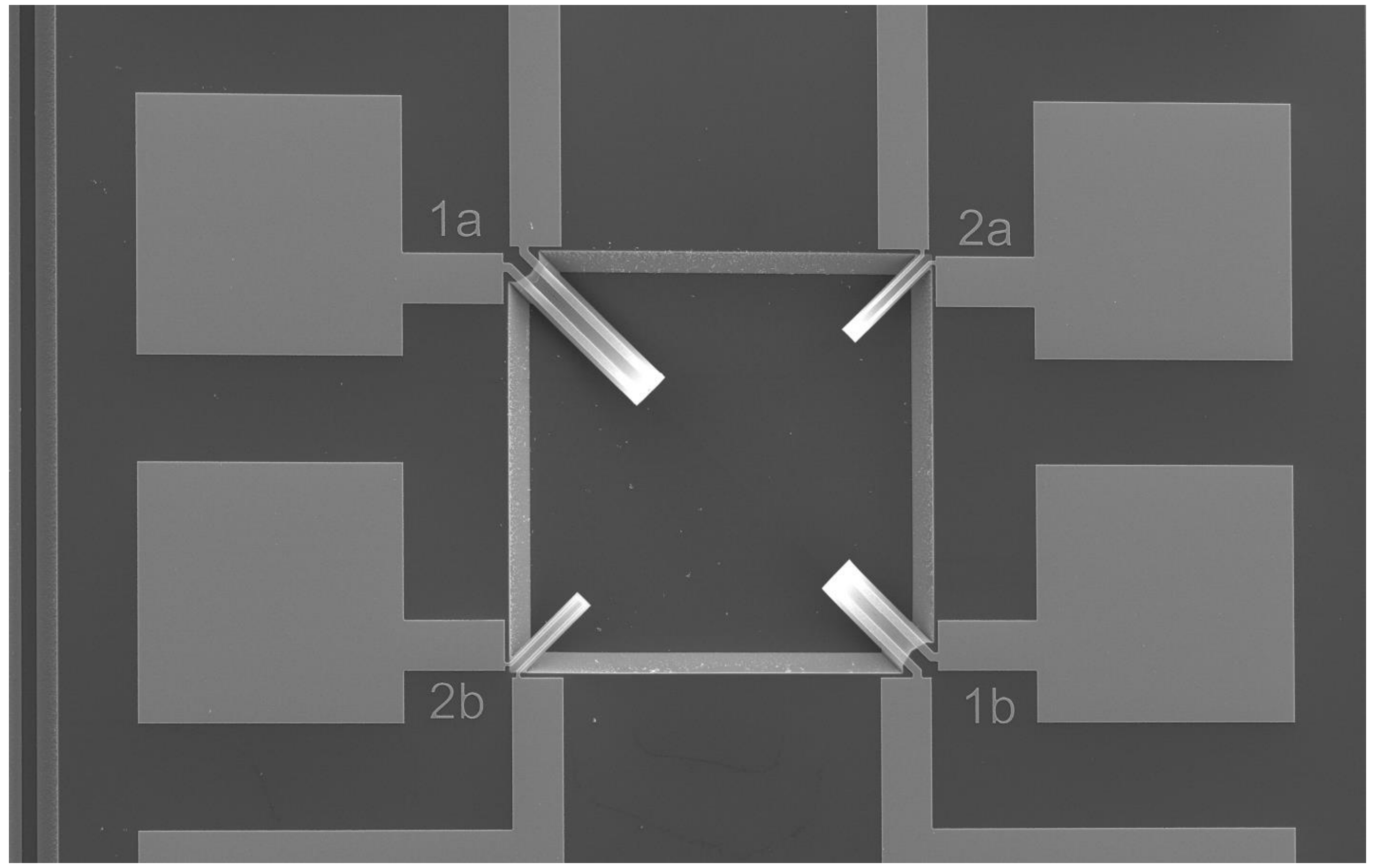

Optical microscope

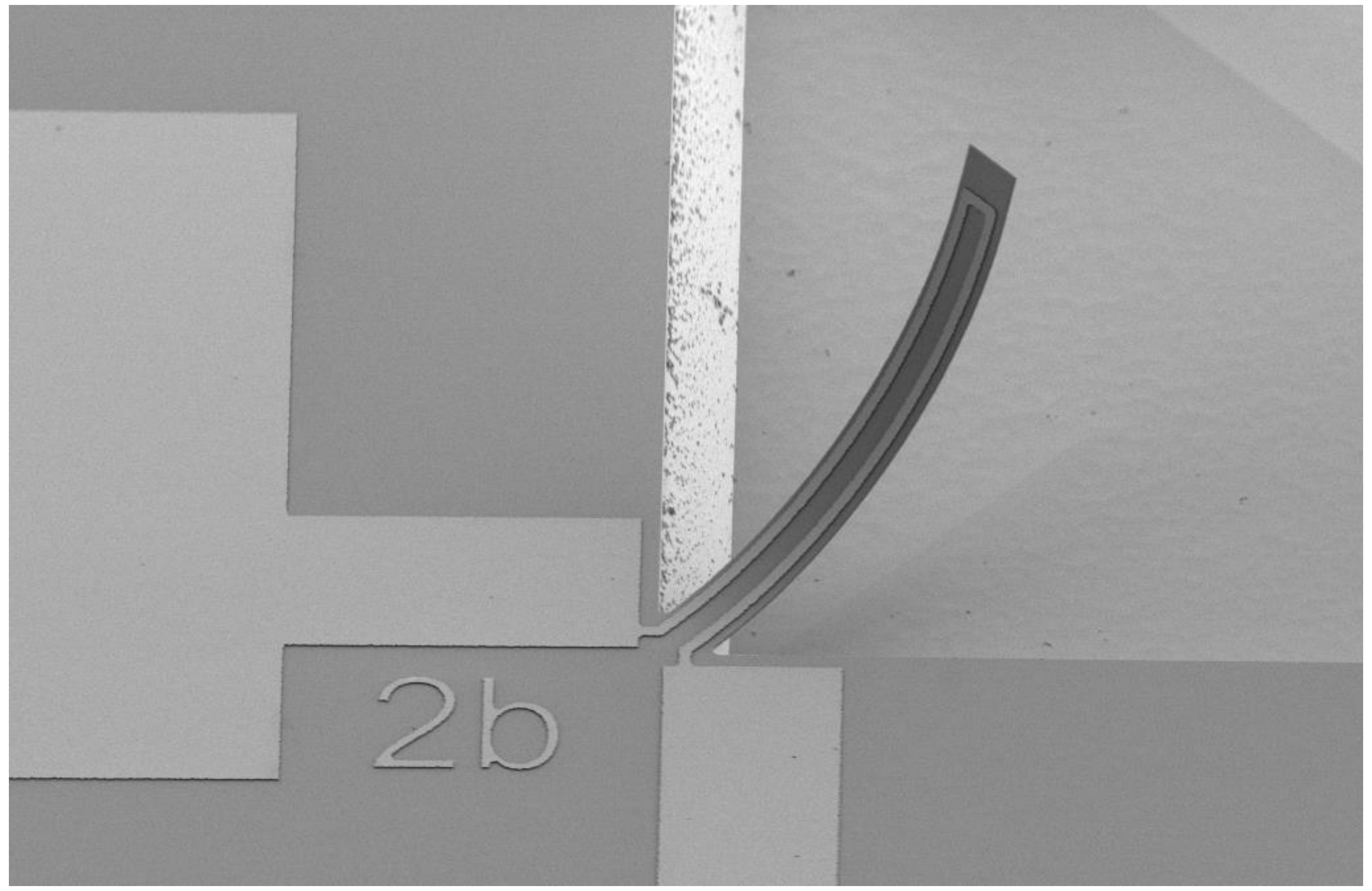



SEM image

# Full wafer after finished bi-morph microfabrication

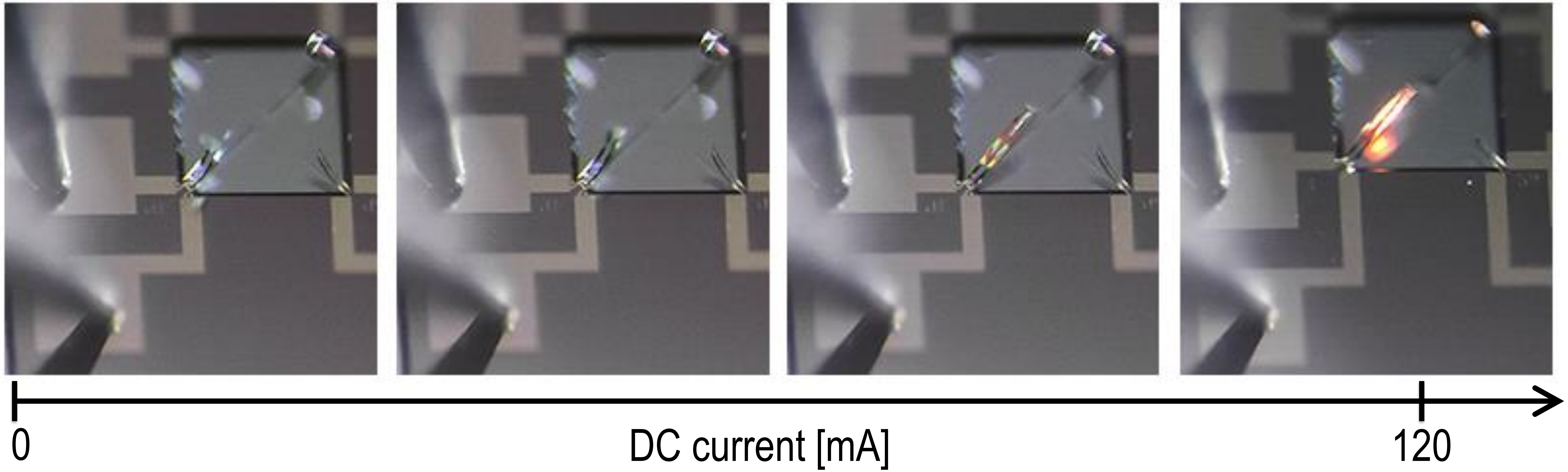


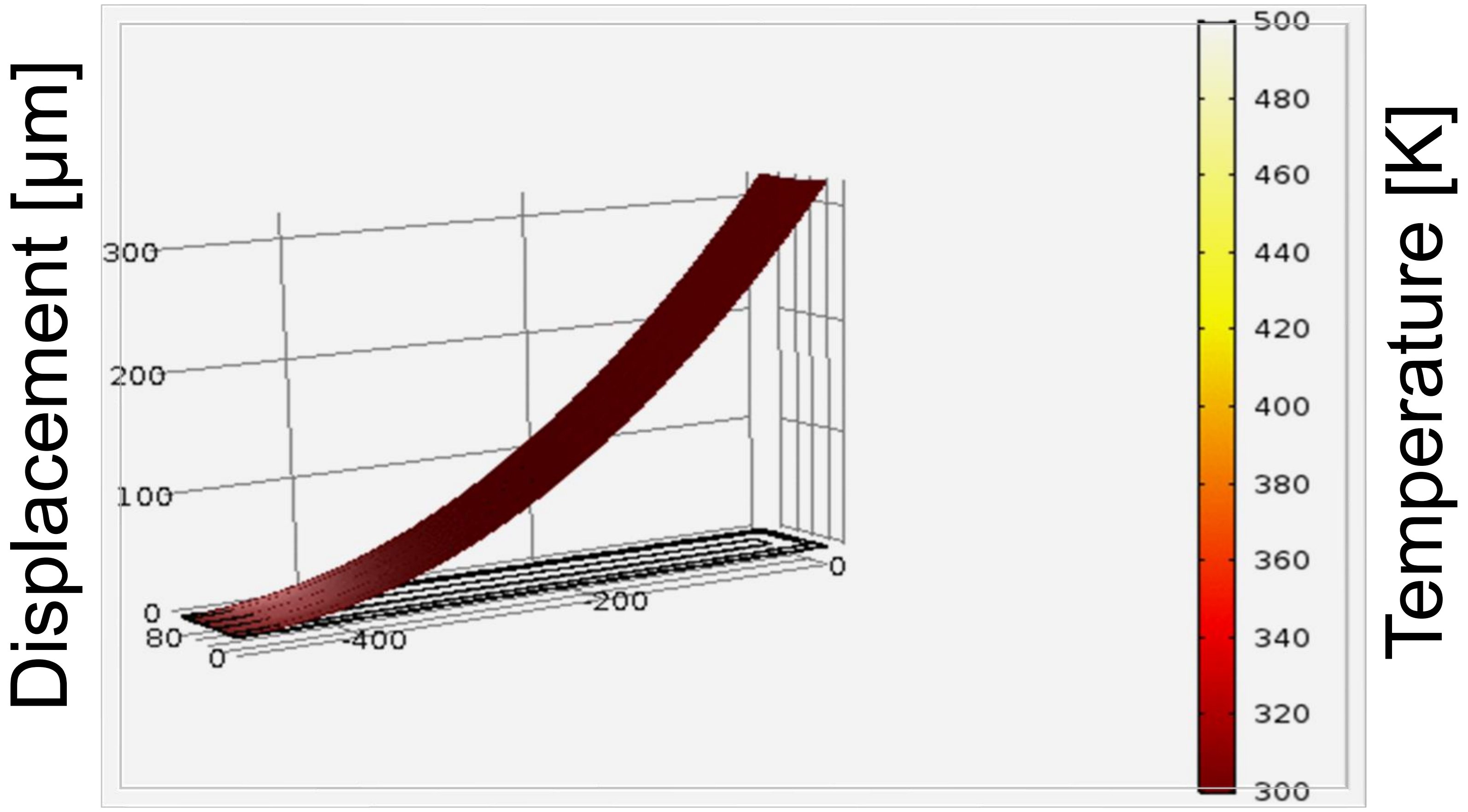
# A4 session

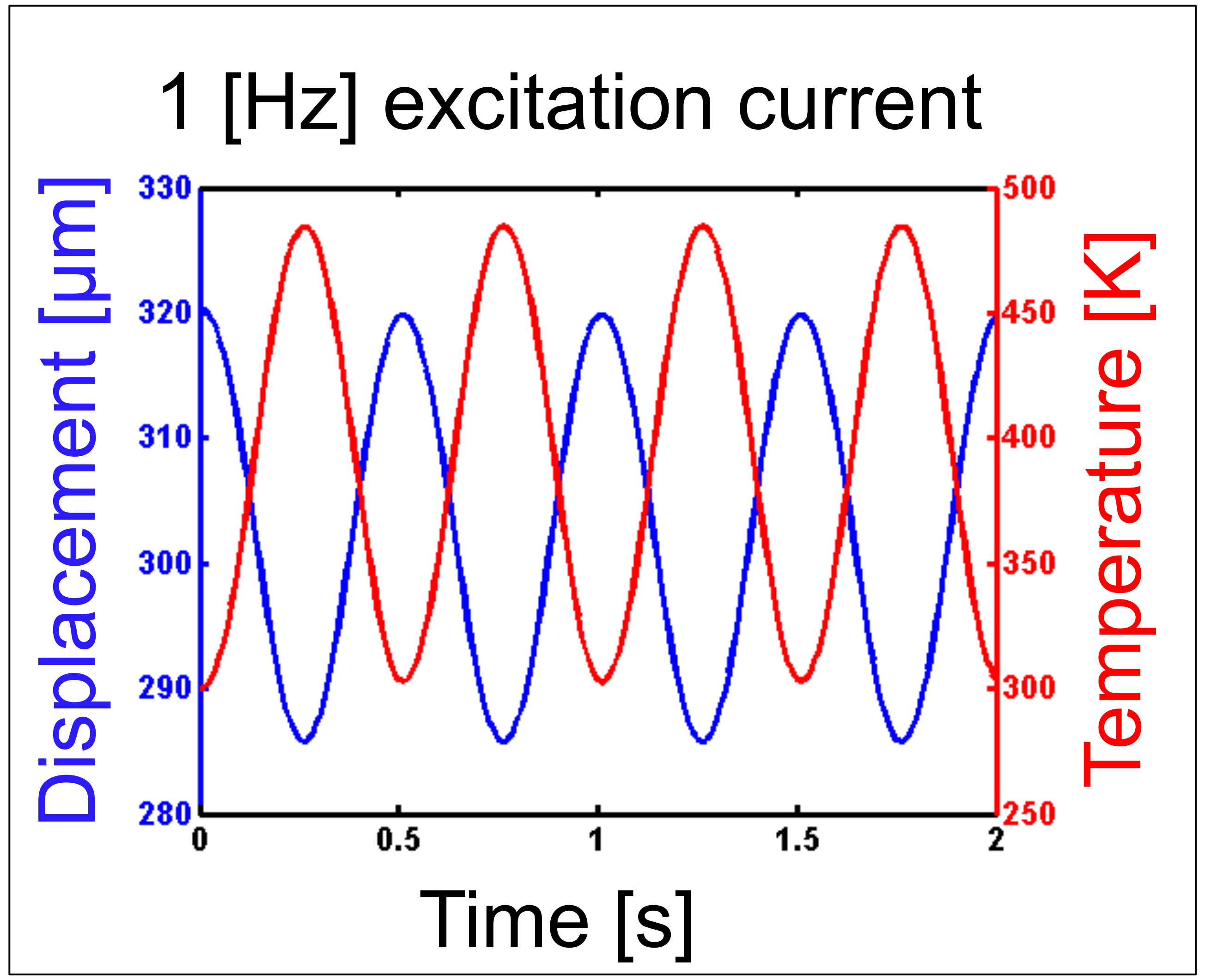
- Characterization of the cantilevers
  - In the LMIS1 lab
  - See the schedule to know your date/TA
  - For organizational reasons, you might do this step before going to the clean room for A2/A3

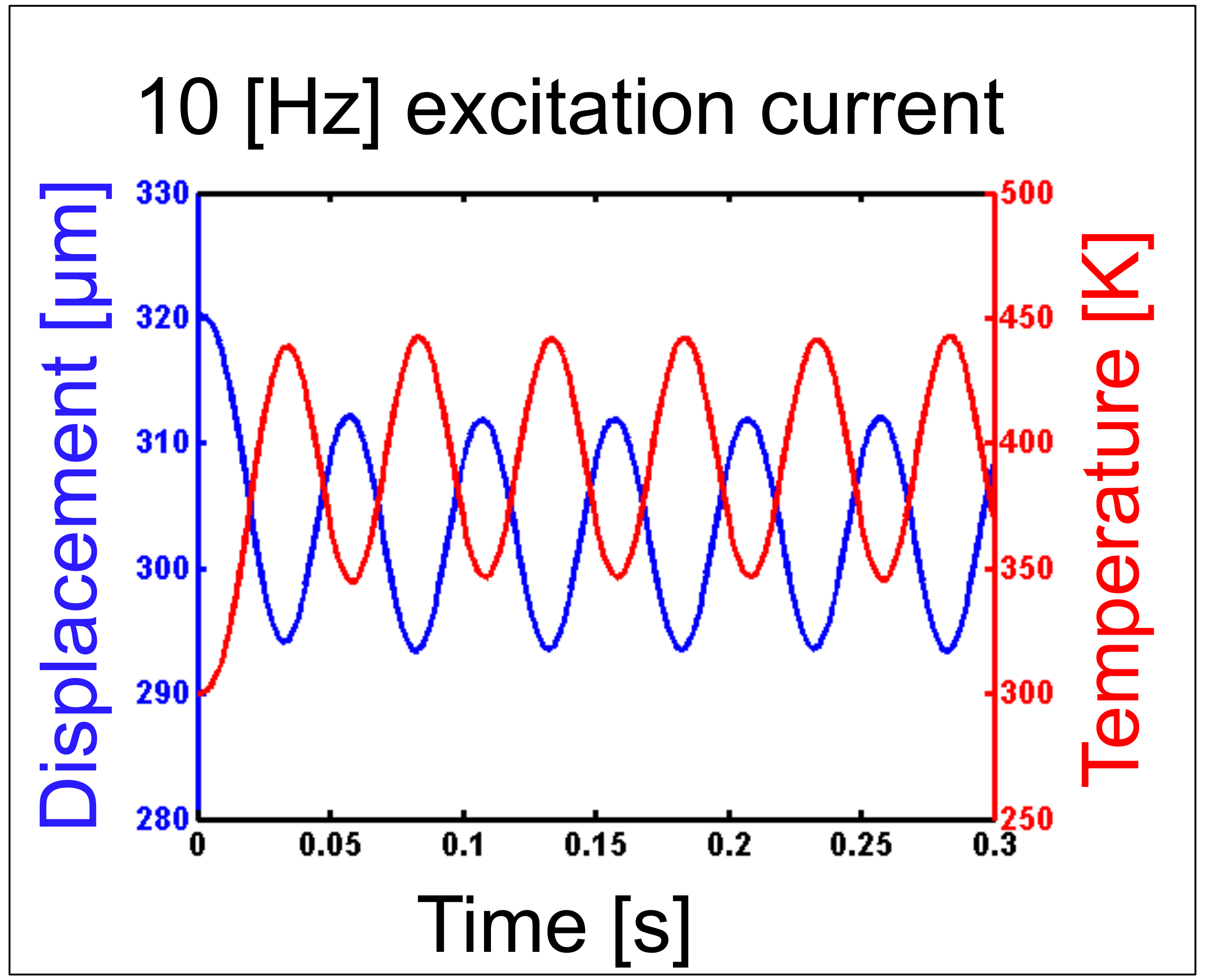


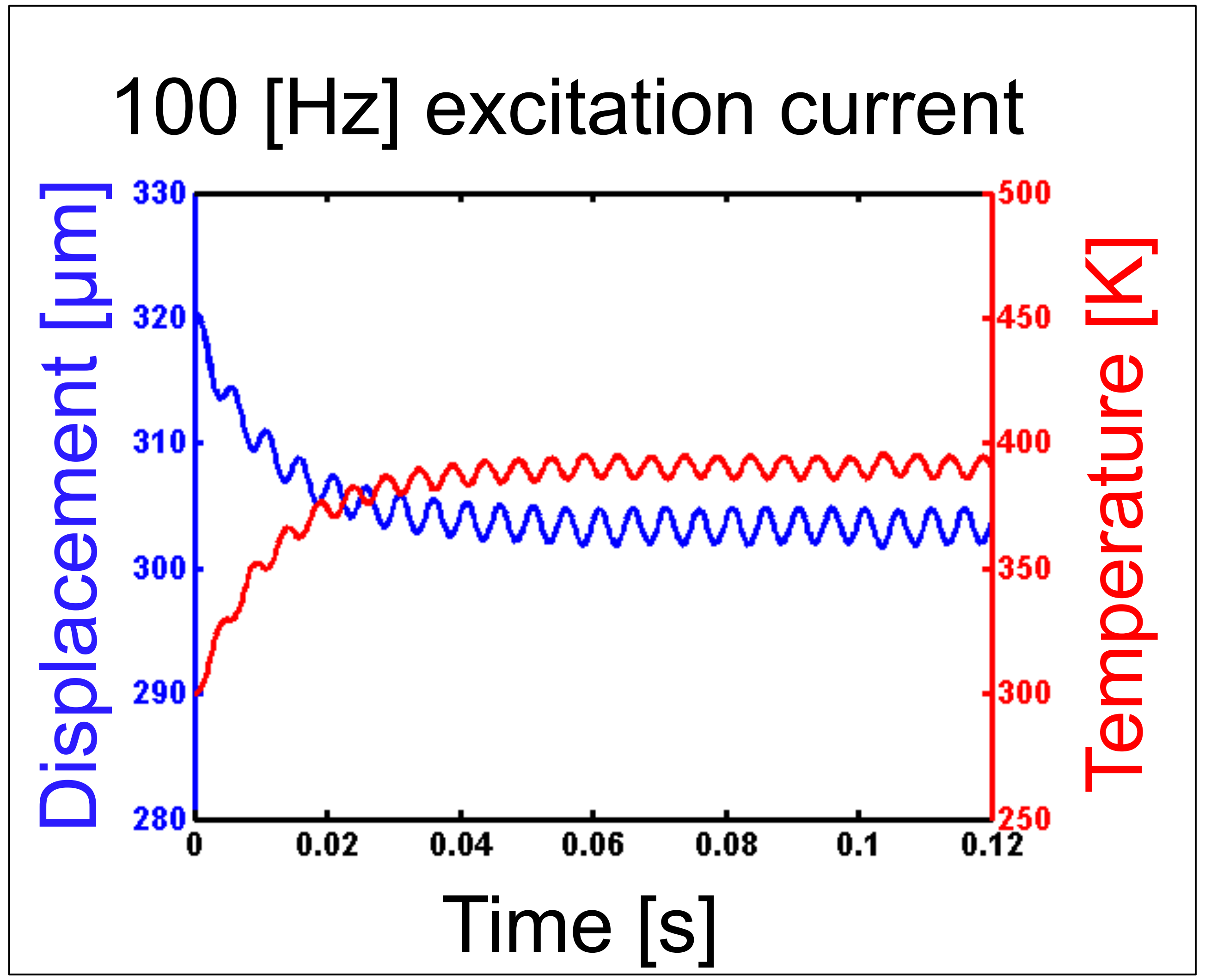
# Thermo-mechanical characterization

- Dynamic [FEM simulation] in TP B
  - AC current in Cr track
  - Oscillation frequency is twice that of the AC frequency
  - Increasing frequency reduces the amplitude



# Final report

- **Submit the final report and all the related files on moodle 1 week after your last TP A session (A4)**
  - Guidelines for the submission of the report are available in the instructions
  - You'll be able to request a feedback when all the reports are corrected at the end of the semester

# A1 theory

1)Verify if you can run/use Klayout (Windows, MacOS, Linux) on your computer and ACES (Windows only, only 1 student per group will need to run it). Let us know if you have any software issue or if everything runs well.

2) Answer the preparation questions 1 to 5 in a short PDF report (that you will name "TPA_2024_Preparation_Group#_Name1_Name2.pdf". Replace # by the group number and Name1, Name2 by the names of the people in your group).

-> Perform tasks 1) and 2) and submit your PDF report to berke.erbas@epfl.ch until Thursday 26.09.2024 at 13h00. You will get feedback during the second A1 session.

# Thermal micro-actuators

EPFL

- Teaching assistants
  - A1 – 2 preparation sessions
    - Berke Erbas
    - André Chatel
    - Chenxiang Zhang
  - A2 & A3 – 1 clean room session at CMi – see schedule
    - André Chatel
    - Chenxiang Zhang
  - A4 – 1 characterization session at LMIS4 – see schedule
    - Sönke Menke
  - Reports and general questions
    - Berke Erbas

# A1 theory

**Questions:**

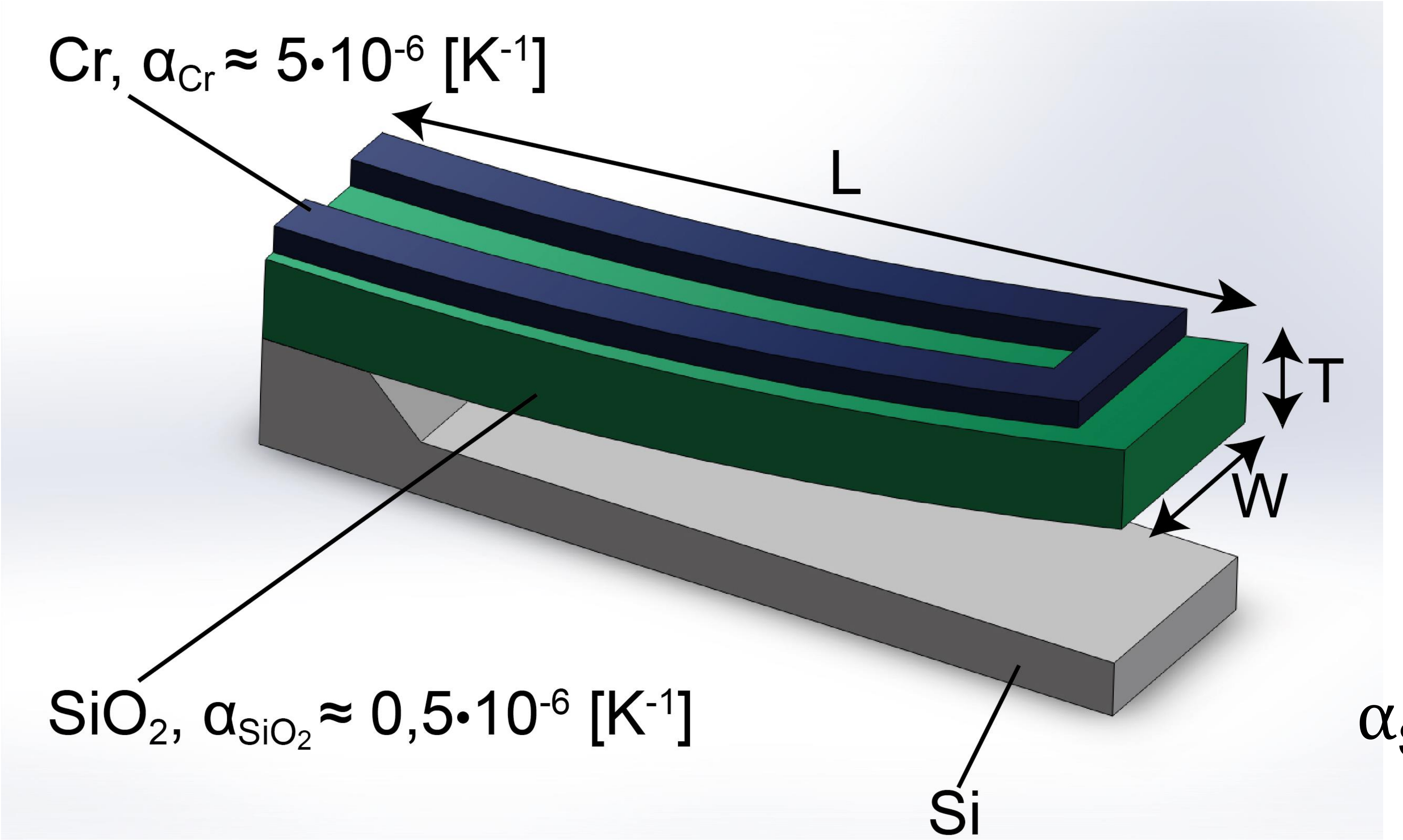
1. Calculate the electrical resistances of the Cr tracks (thickness 500nm) for the 2 standard cantilevers 1a and 2a.
   a. Let's say you apply a DC voltage V across the electrical track, how much power will be dissipated by Joule heating?
   b. How much power will be dissipated if you apply a sinusoidal AC voltage V?

2. From the literature, find the oxidation time to obtain 1µm of oxide at 1050°C.
   a. Why are we using wet oxidation and not dry oxidation?
   Refer to the CMi website (CMi Centrotherm Furnaces) and to the references to answer that question.

3. In which direction will the cantilever bend initially, at 20°C, just after the release by KOH etching? Provide a schematic and a qualitative answer about the internal stress in materials. The references will help you answer that question. Think about the growth/deposition process.

# Questions session A1 - Hint

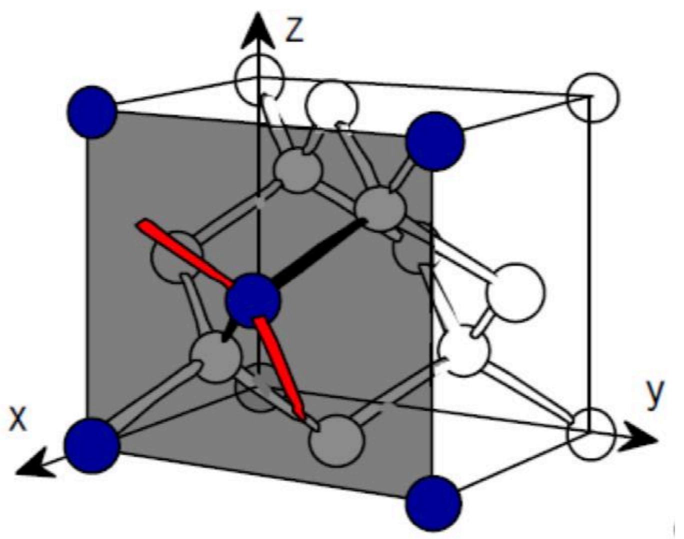
- Question 3
  - Think about the thermal stress, the thermal expansion coefficients of the materials and the deposition conditions




$\alpha_{Si}$~2,6*10^-6 [$K^{-1}$]

# A1 theory

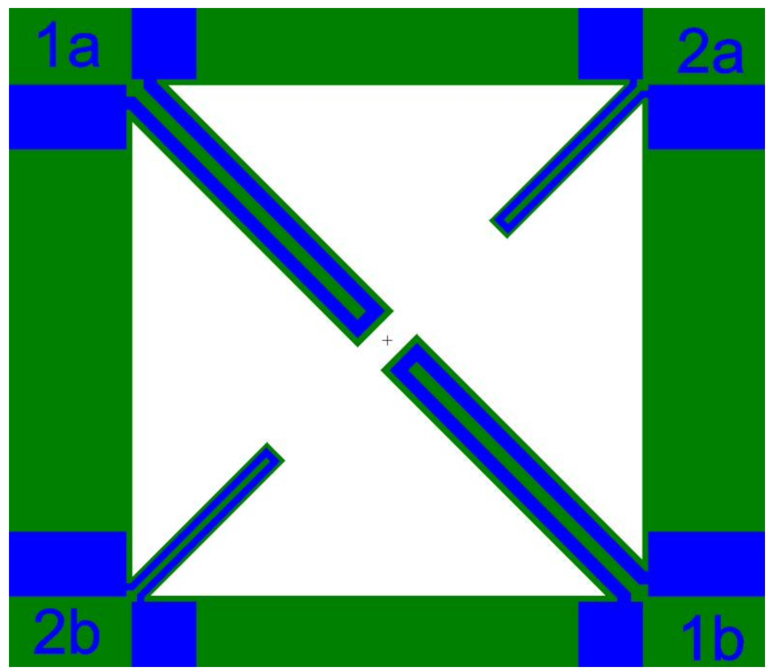
4. Explain how KOH etching of silicon works, why it's anisotropic.
    a. Explain why the cantilevers are in the corners of a square and explain why the orientation of the square with respect to the crystal planes of silicon is of importance; which crystal plane (Figure 6)?
    b. What would it change in terms of KOH etching if we were to put the cantilevers on the sides of the square (Figure 7)?
    (The references will help you answer that question. Remember that when discussing geometrical matters, a schematic is always a good idea.)




(100)面

Dangling bond : **2**

Back bond : **2**



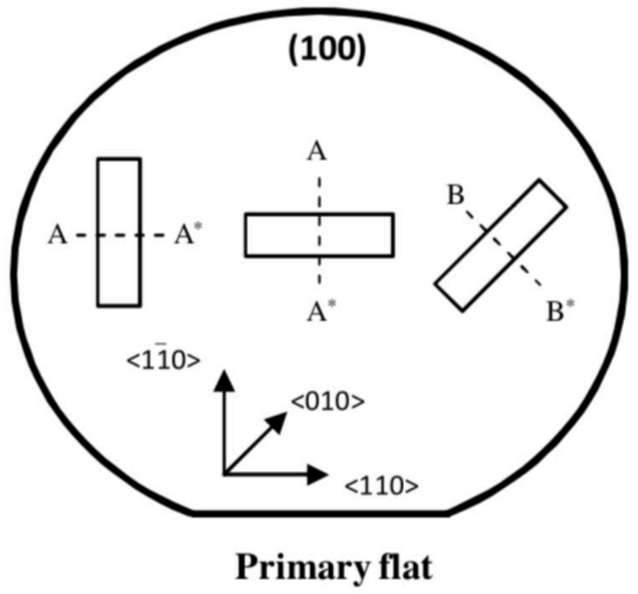




*Figure 6 Orientation of the silicon crystal on the wafer used in this practical (reproduced from [11]).*

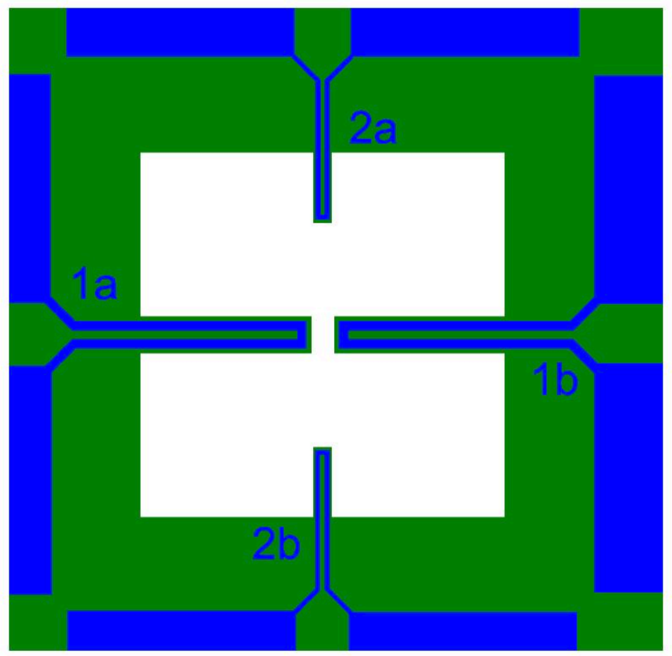



*Figure 7 Cantilevers on the sides of the square.*

# A1 theory – question 5

EPFL

➔ Estimate the resonance frequency of both standard micro-fabricated cantilevers 1a and 2a (see design in Figure 5).

➔ To do so, use the formulas below.

➔ An approach you can follow consists in transforming the 2-material structure into an equivalent 1-material structure as described in the section § 9.1 *Composite Cross-Sections* of the reference [13].

➔ You'll also need to evaluate the total area moment of inertia for the two materials.

➔ Report the total area moment of inertia I, the spring constant k, the mass of the structure m and the resonance frequency f.

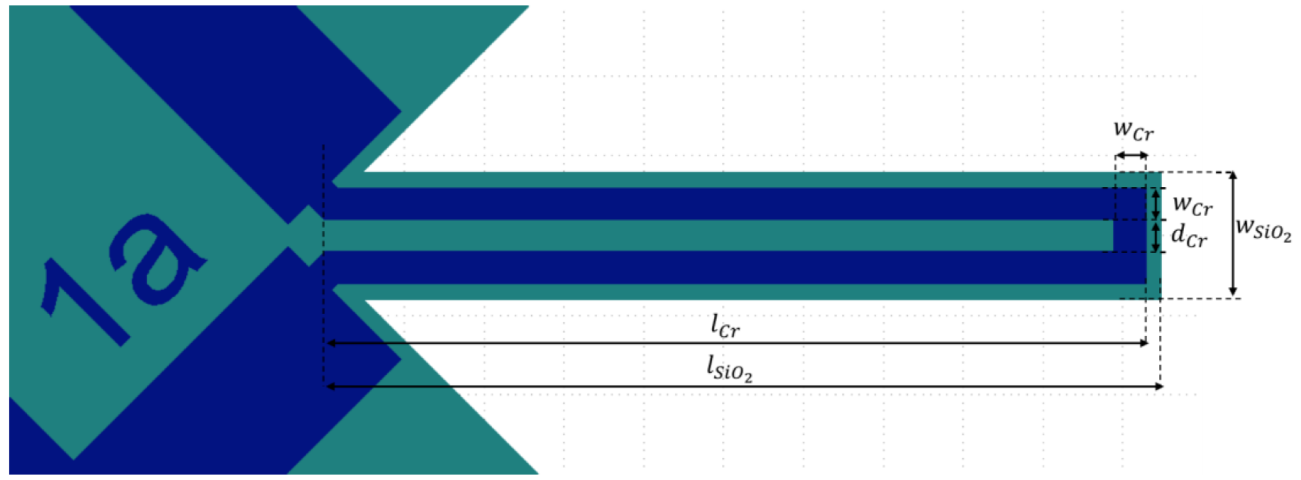
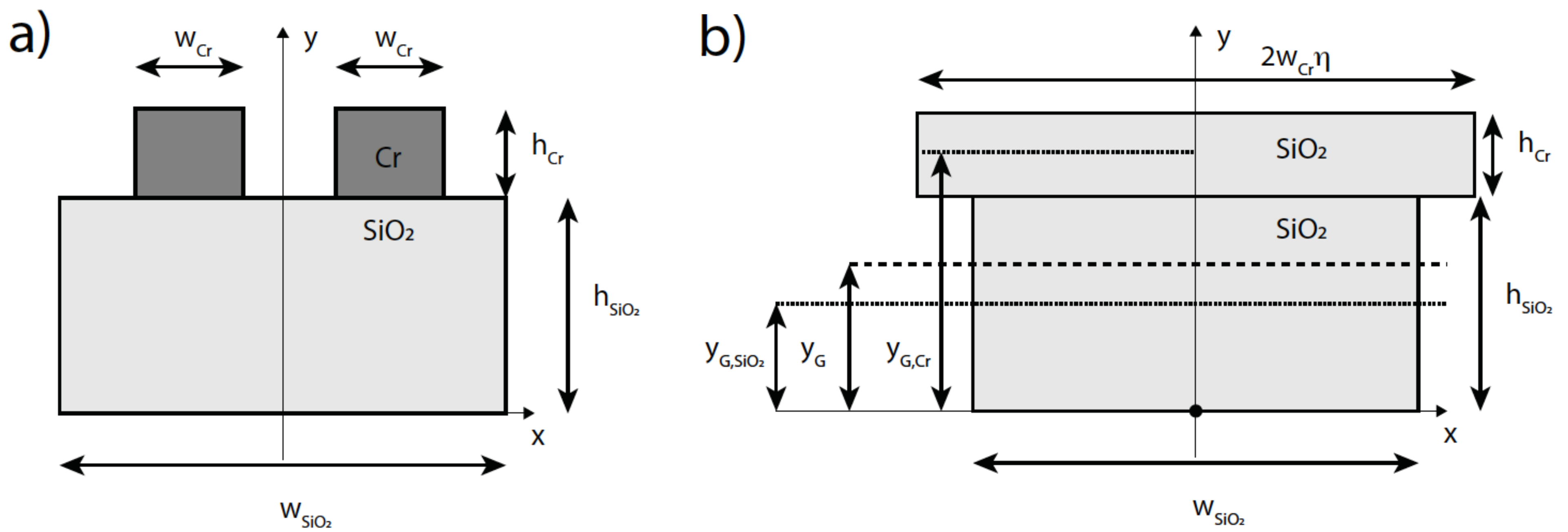
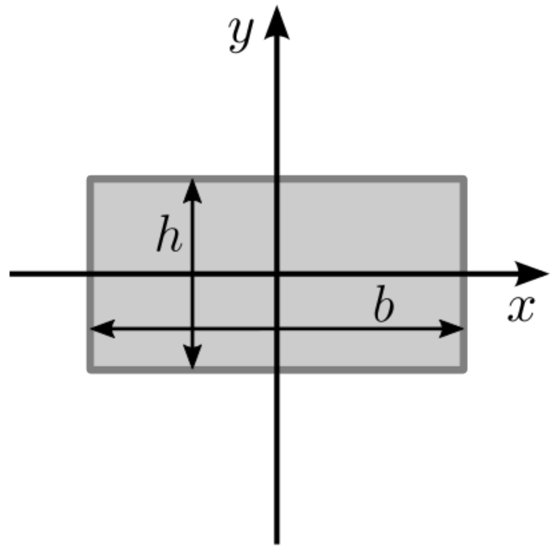


Figure 5 Dimensions of the actuator 1a.

$$\omega = \sqrt{\frac{k_{cantilever}}{\alpha\, m_{beam}}}$$

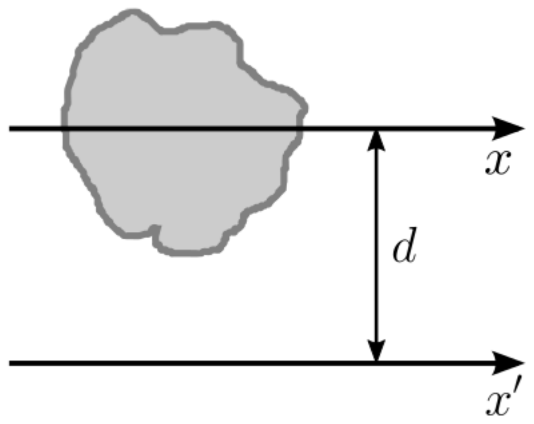
$$k_{cantilever} = \frac{3EI}{l^3}$$




$$I_x = \frac{bh^3}{3}$$

$$I_y = \frac{b^3 h}{3}$$



# A1 theory – test softwares for next session

- **Klayout – to design the cantilevers**
  - Install (Linux, MacOS, Windows)
  - Open TP_A-Standard4.GDS
    - Configure it in editor mode and try to add/delete/modify any feature

  ➔ Does it work?

- **ACES – to simulate the KOH etching process**
  - Install (Windows only)
  - Download the folder ACES
  - Run the executable ACES.exe

  ➔ Does it work?