The way of thick films toward a flat Q in sputtered cavities

道

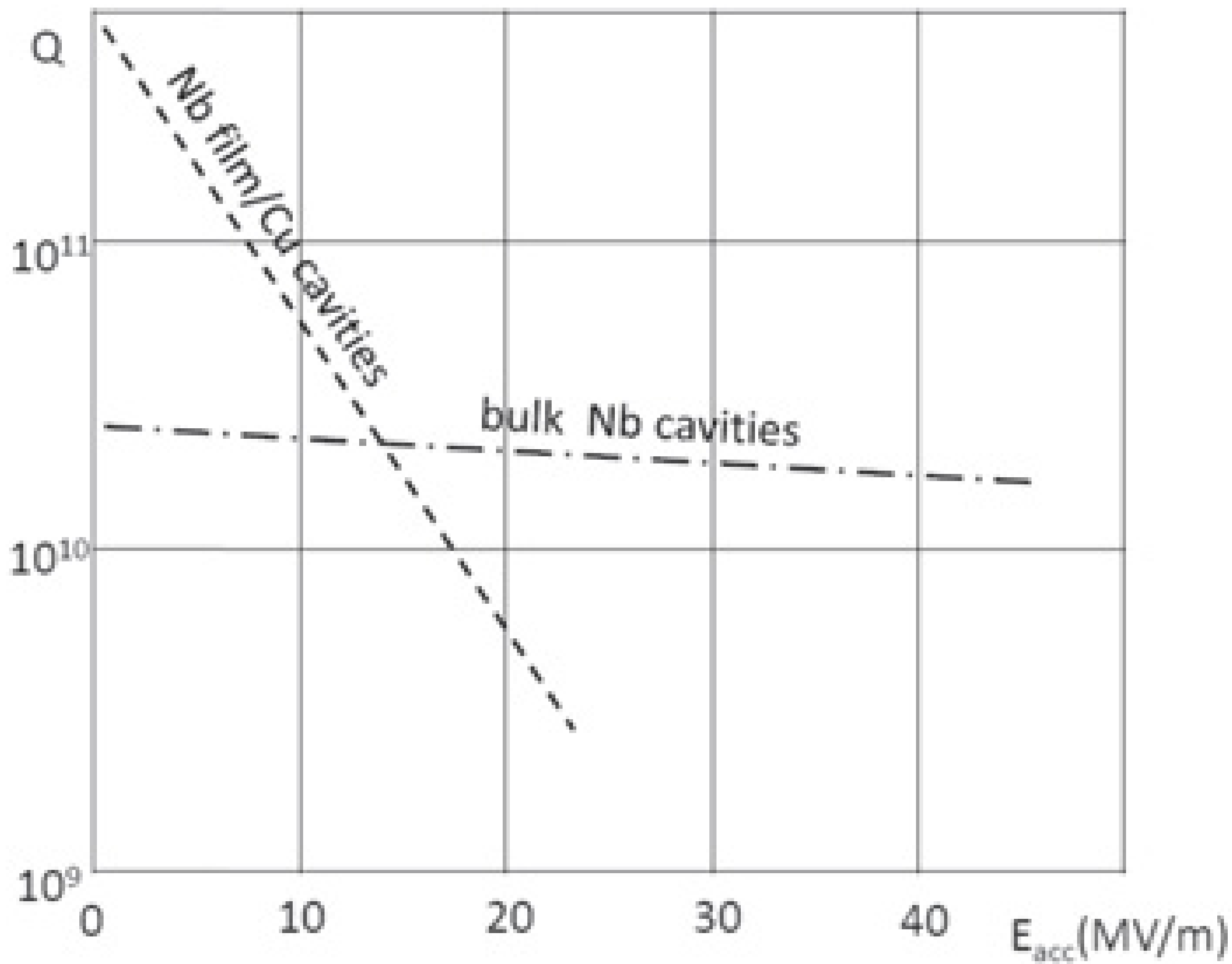
V. Palmieri*, G. Caldarola*, S. Cisternino*, D.A. Franco-Lespinasse*,

C. Pira*, H.Skliarova°, F. Stivanello*, R. Vaglio°^

In the framework of CERN-INFN-FTSC Agreement N. KE2722/BE/FCC

The Q slope in thin film sputtered cavities

(@ 1.5 GHZ and 1.8 K)



Part 1

Why thick films?

The Experimental Evidence

- **Nb sputtered Cu:** **Display Q-slope**

- **Nb clad Cu:** **No Q-slope**

In what clad cavities differ from sputtered ones?

- **Nb Thickness** → **Bulk-like properties:**
  - **film purity**
  - **grain size**

  → **High RRR**

- **Nb-Cu Interface** → **Explosively interdiffused material**

How **Nb thickness** could affect RF performances?

1. Possible Physical mechanism:

Superconducting gap depends on n_s/n

$$\Delta = \Delta_0 - P_F V_s$$

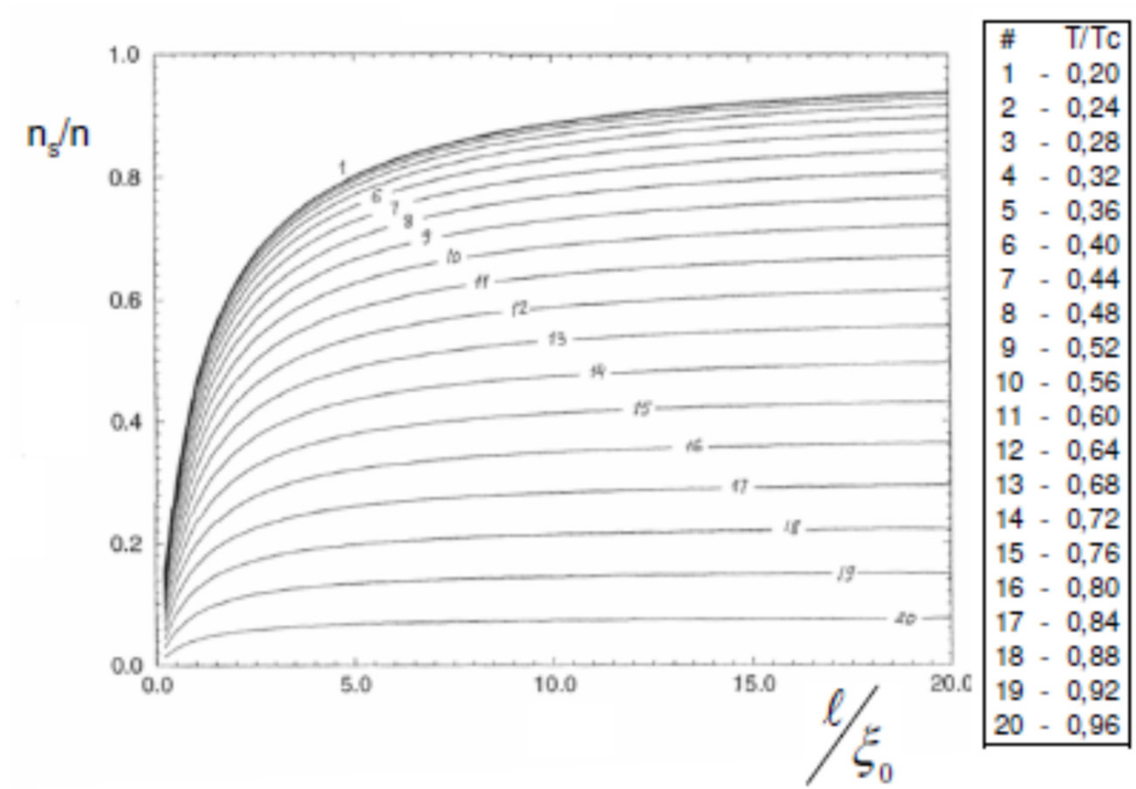
$$V_s = V_s\,(n_s/n)$$

V. Palmieri, " The Problem of Q-drop In Superconducting Resonators Revised by the Analysis of Fundamental Concepts from Rf-superconductivity Theory" Proceedings of the 12th International Workshop on RF Superconductivity, Cornell University, Ithaca, New York, (2005) USA

1. Possible Physical mechanism:

Superconducting gap depends on n_s/n

$$\frac{n}{n_S} = \cot gh\left(\frac{\ell}{\xi_0}\right)$$

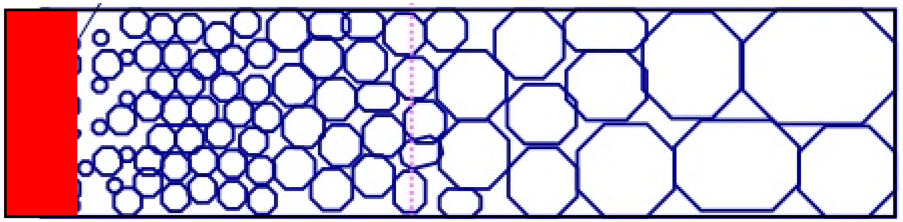


V. Palmieri, Proceedings of the 12th International Workshop on RF Superconductivity, Cornell University, Ithaca, New York, (2005) USA

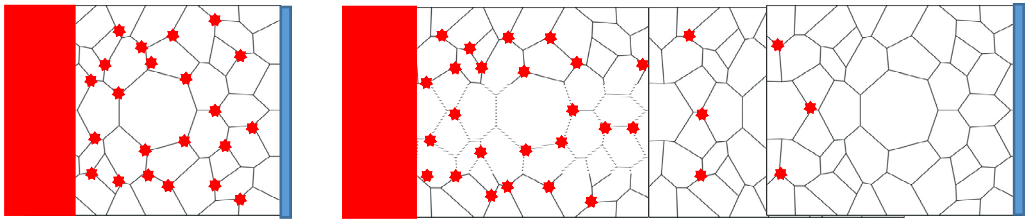
High Nb Thickness can provide RRR>100

because of

- **Large grain growth**



- **The film top layer is farer from Nb/Cu Interface**



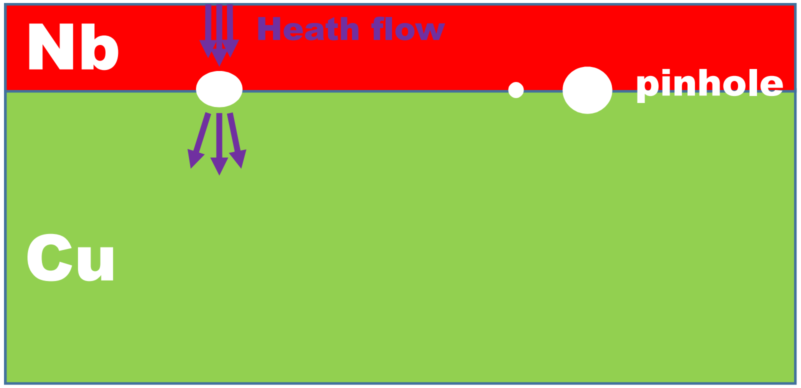
a) b)

(the larger thickness damps impurity diffusion from interface)

2. Possible Physical mechanism

Suggested by S. Calatroni from CERN:

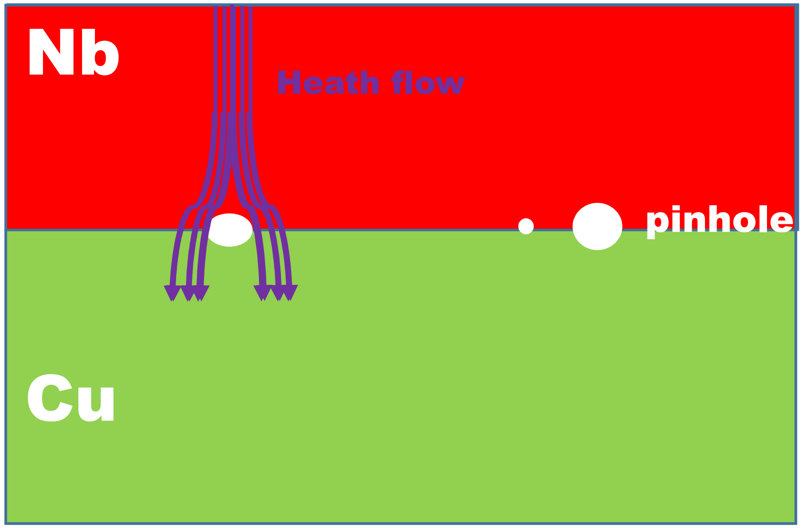
In thin films, in a case of a defect, the thermal flow propagates from Nb to Cu almost one-dimensionally



2. Possible Physical mechanism

Suggested by S. Calatroni from CERN:

In **thick** **films, the thermal flow shunts the defect, propagating from Nb to Cu with higher efficiency**



3. Possible Physical mechanism

A defected thermal contact at the Nb-Cu interface is responsible of the Q-slope

3. Possible Physical Mechanism

The quality of interface

depend on film stress,

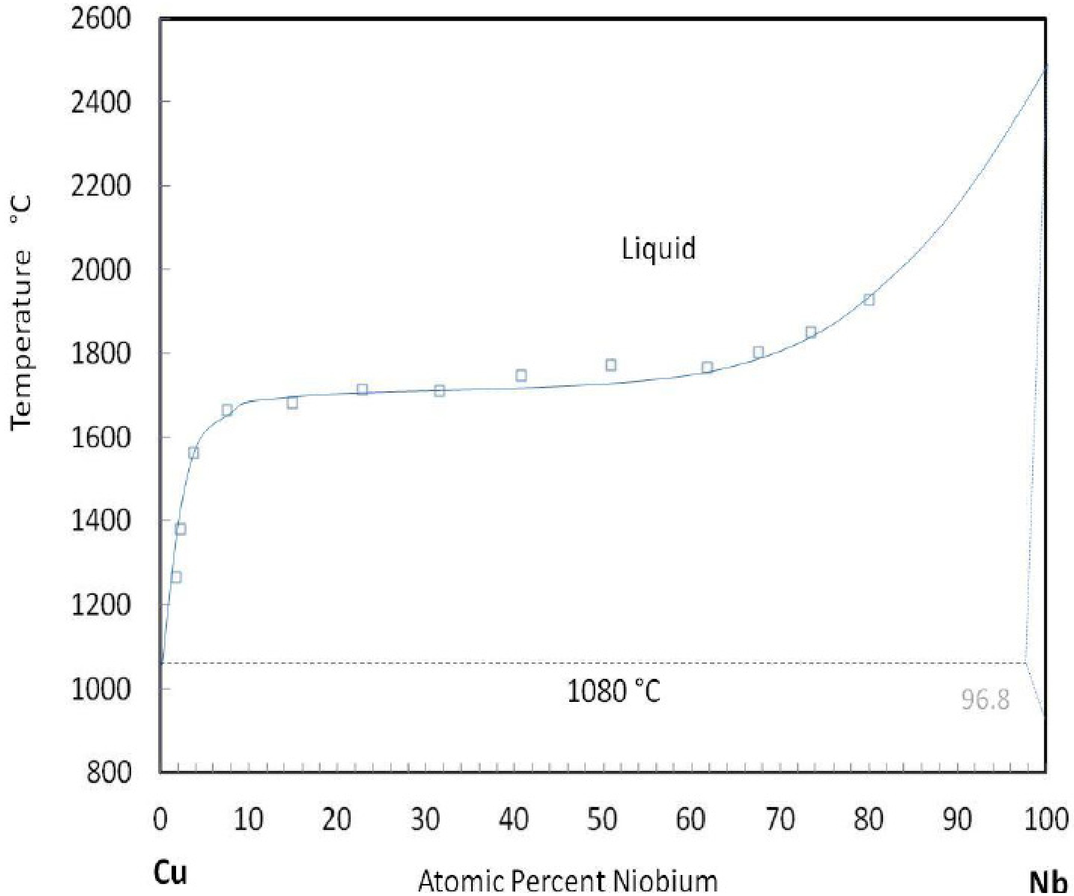
.....

even more if Nb and Cu are not miscible!!

3. Possible Physical mechanism

The Cu-Nb phase diagram

(after D.J. Chakrabarti and D.E. Laughlin)



3. Possible Physical Mechanism

Only if the film is not stressed, one will be sure that a thick film will be adherent to the interface

Hence, ….

There are different considerations pushing to try to deposit thick films rather than thin films

because eventually, ...

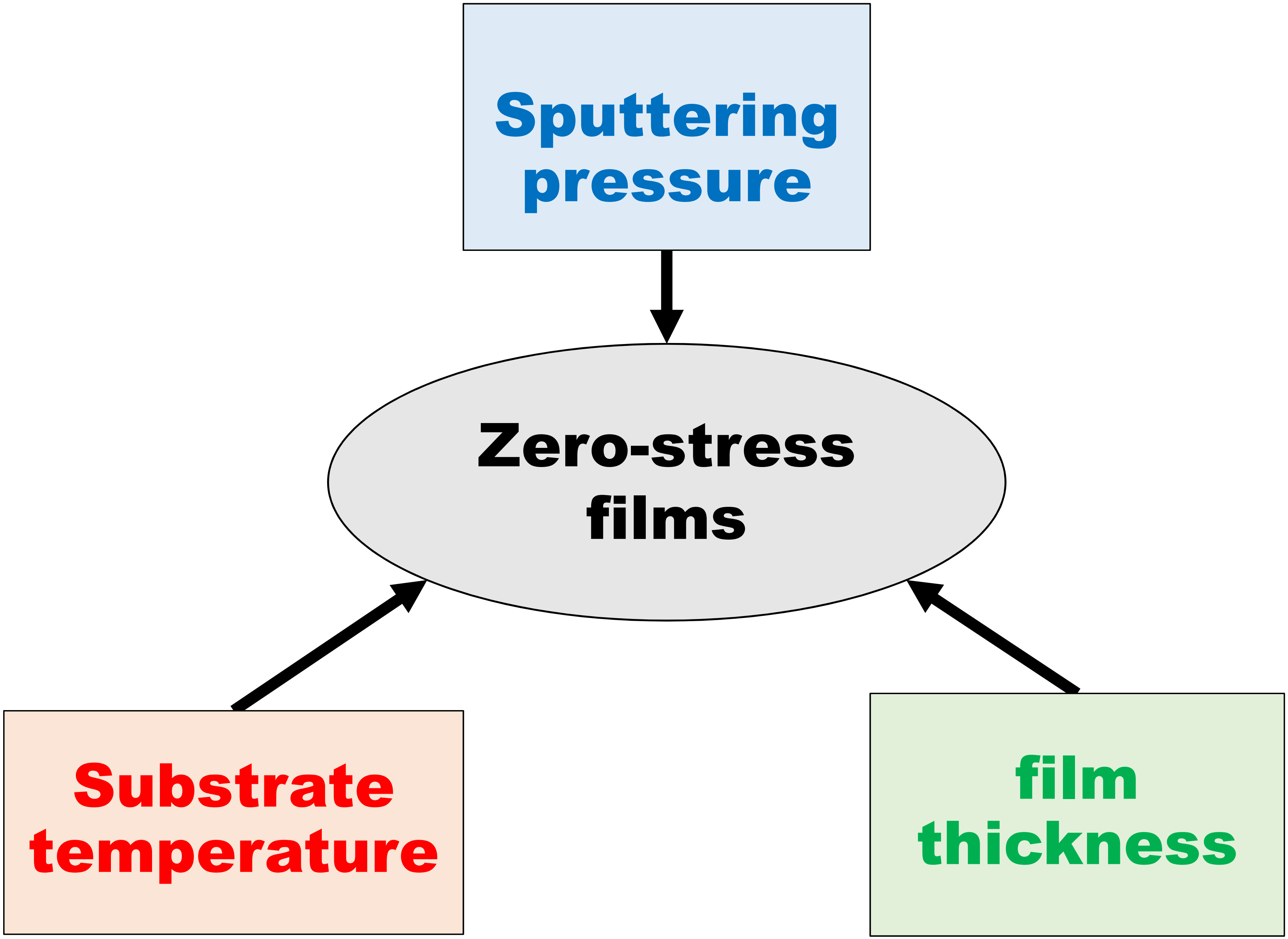
thick films imply:

- **higher purity**
- **better interface**

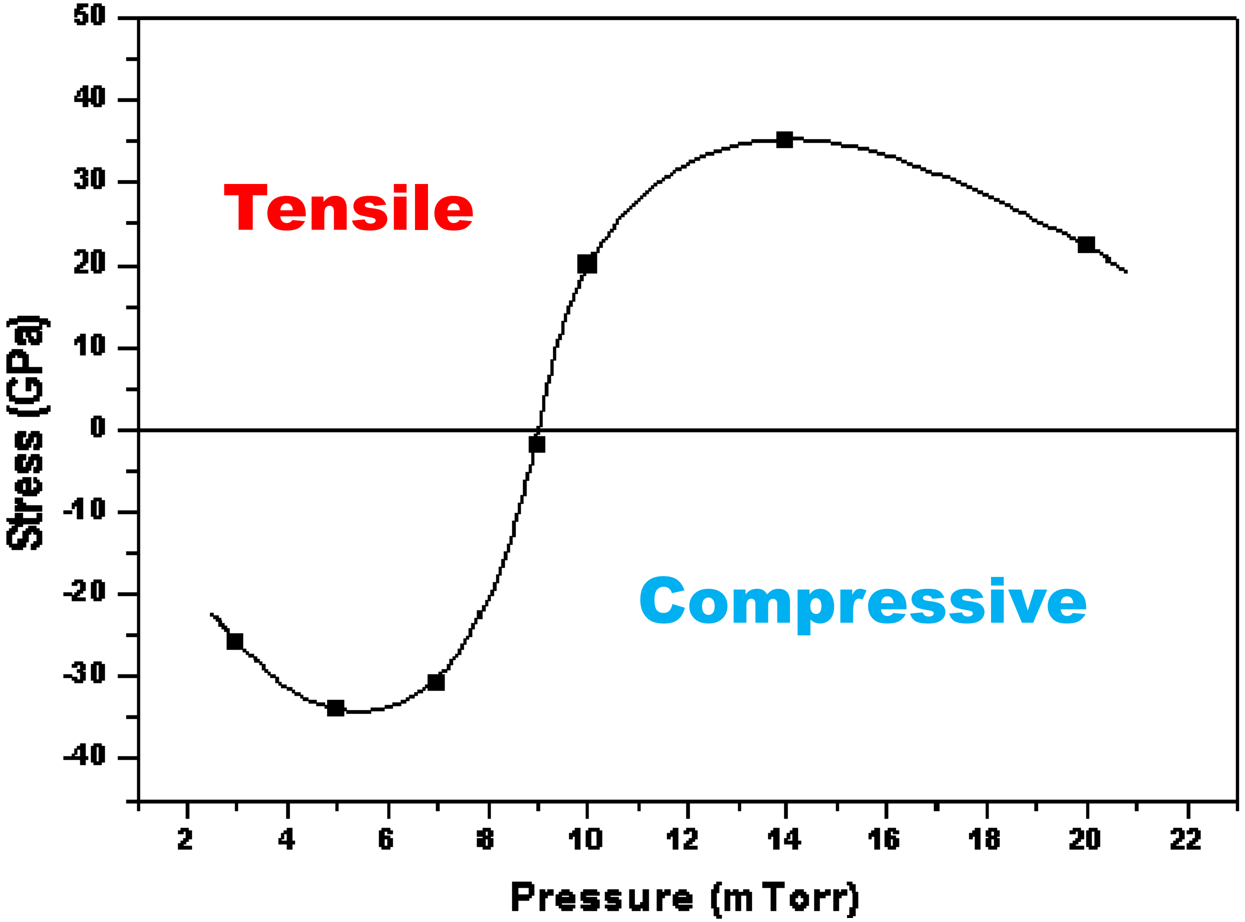
Part 2

道

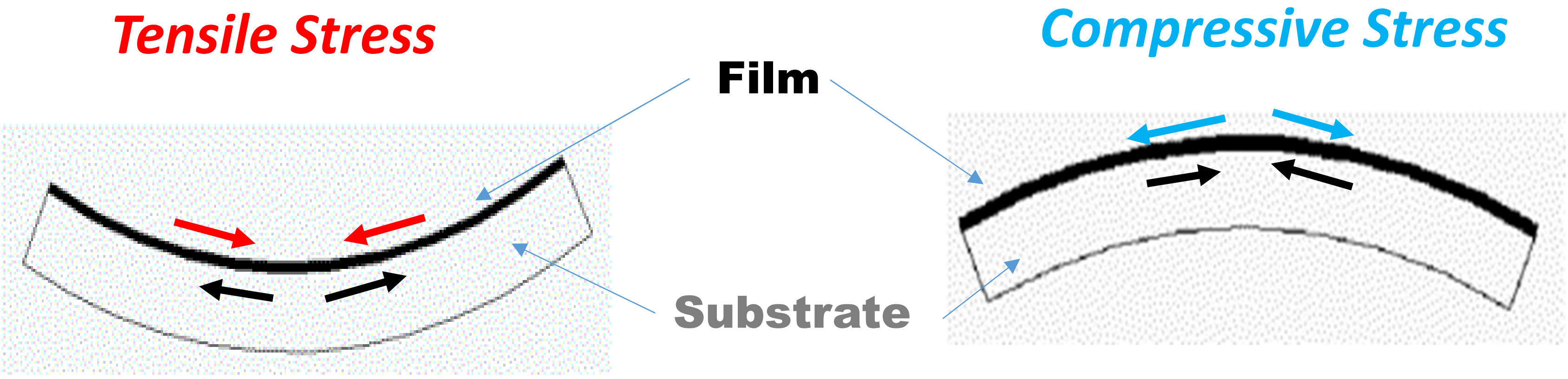
Experimental proceedure


Sputtering pressure
Zero-stress films
Substrate temperature
film thickness

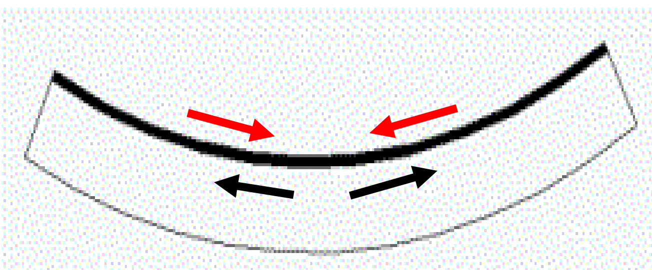
Stress in thin films



Stress in thin films

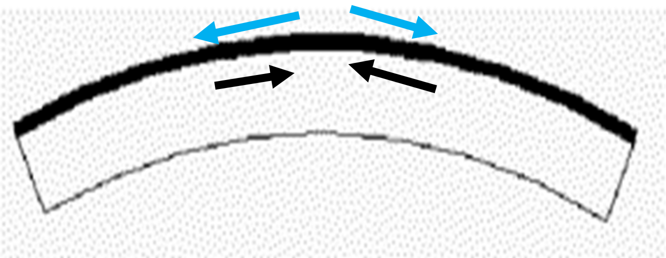


Stress in thin films



Tensile Stress

Compressive Stress



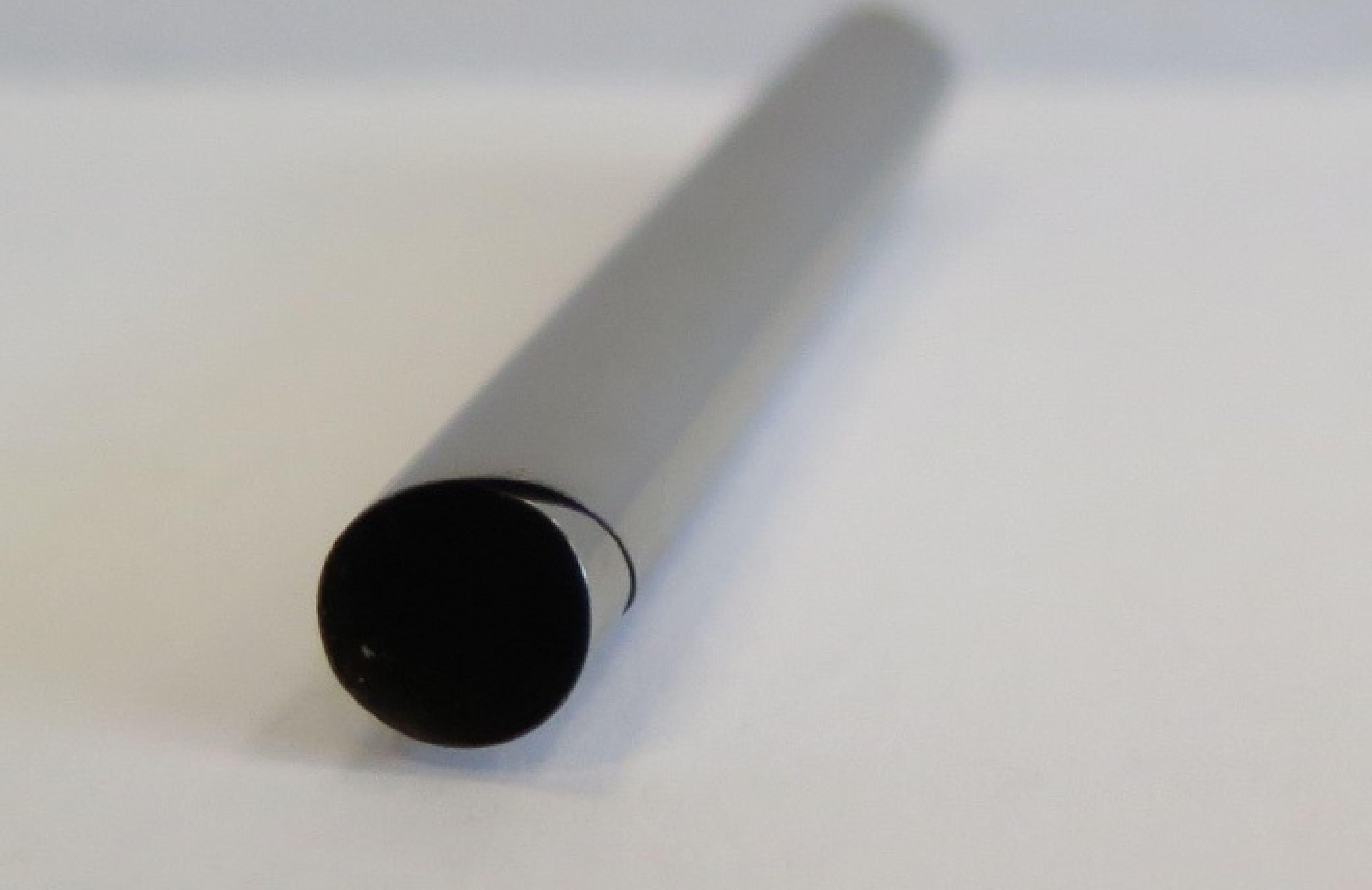
Film is smaller than substrate.

In order to grow onto the substrate the film must adapt to it under tensile forces

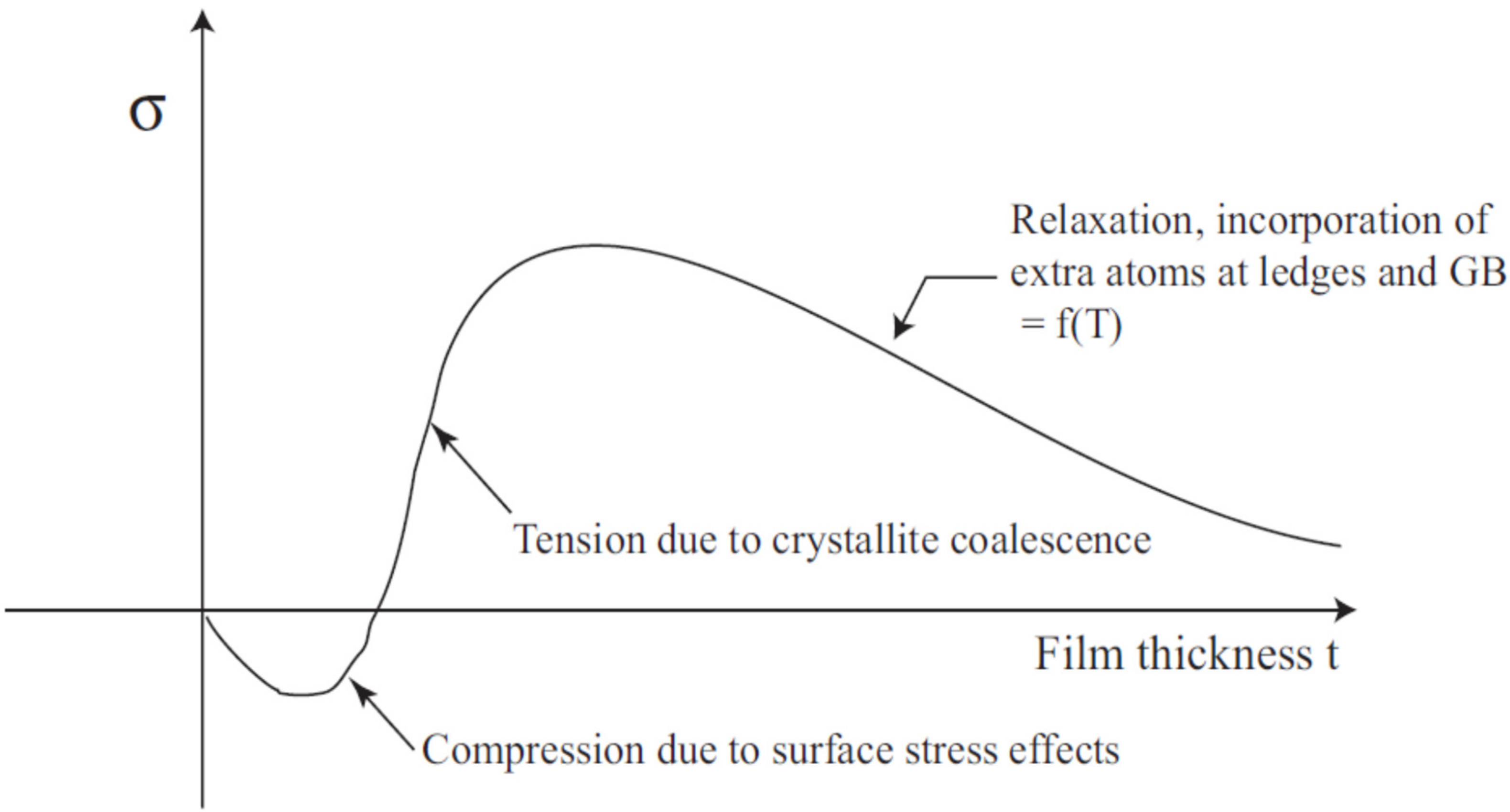
Film is larger than substrate.

In order to grow on the substrte, the film must adapt to it under compressive forces

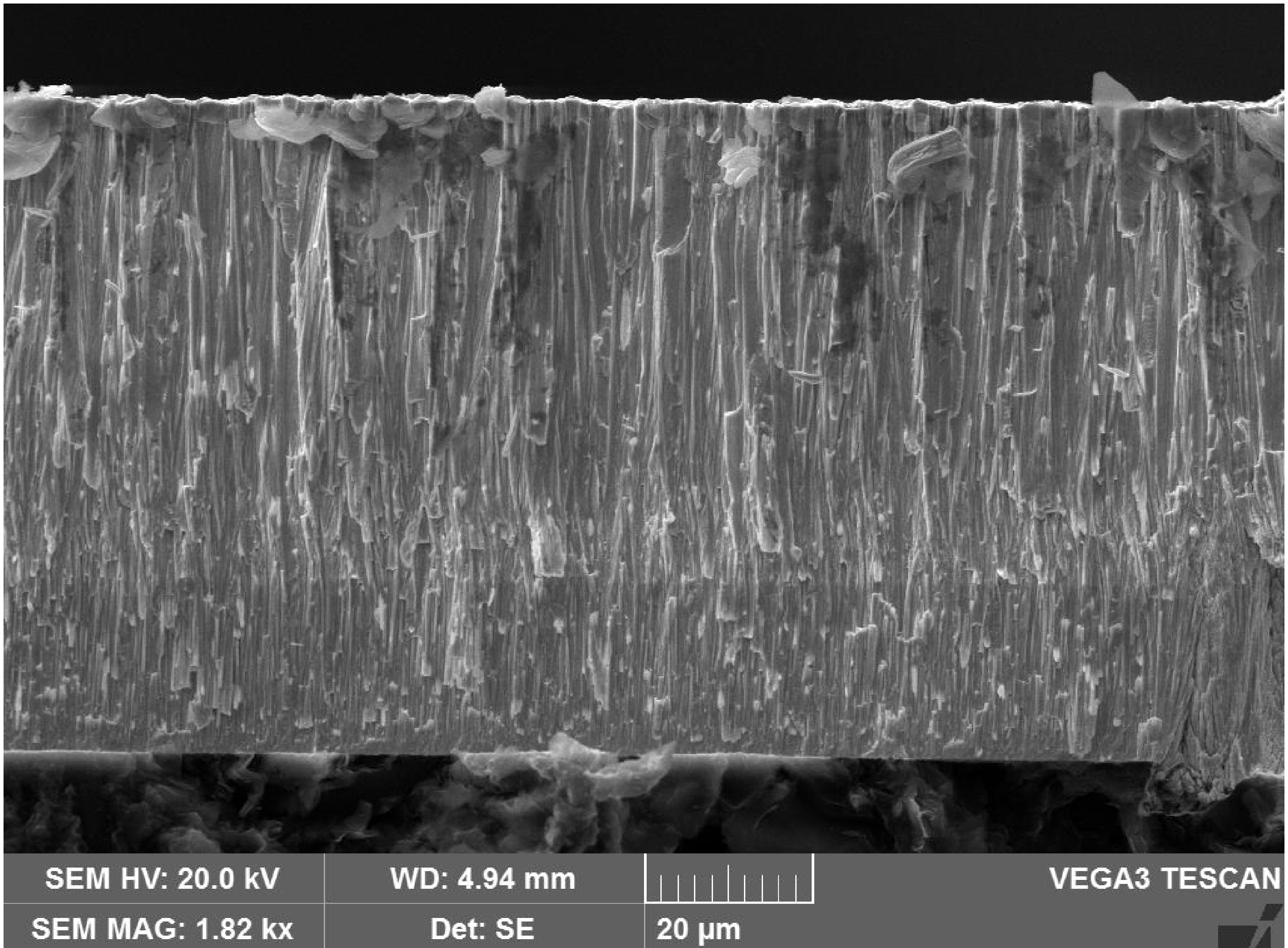
How to measure the film stress?



Film stress versus film Thickness



A new sputtering method to obtain hundreds micron thick Nb films



You deposit a thin layer of a few hundreds of nanometers, ...

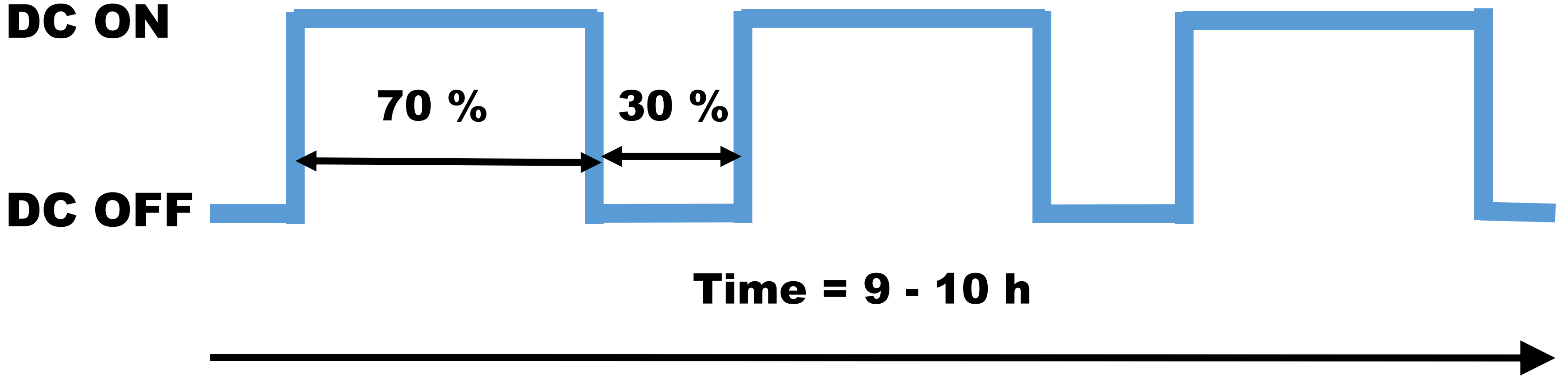
than you stop the process,

giving to the film the time to renormalize.

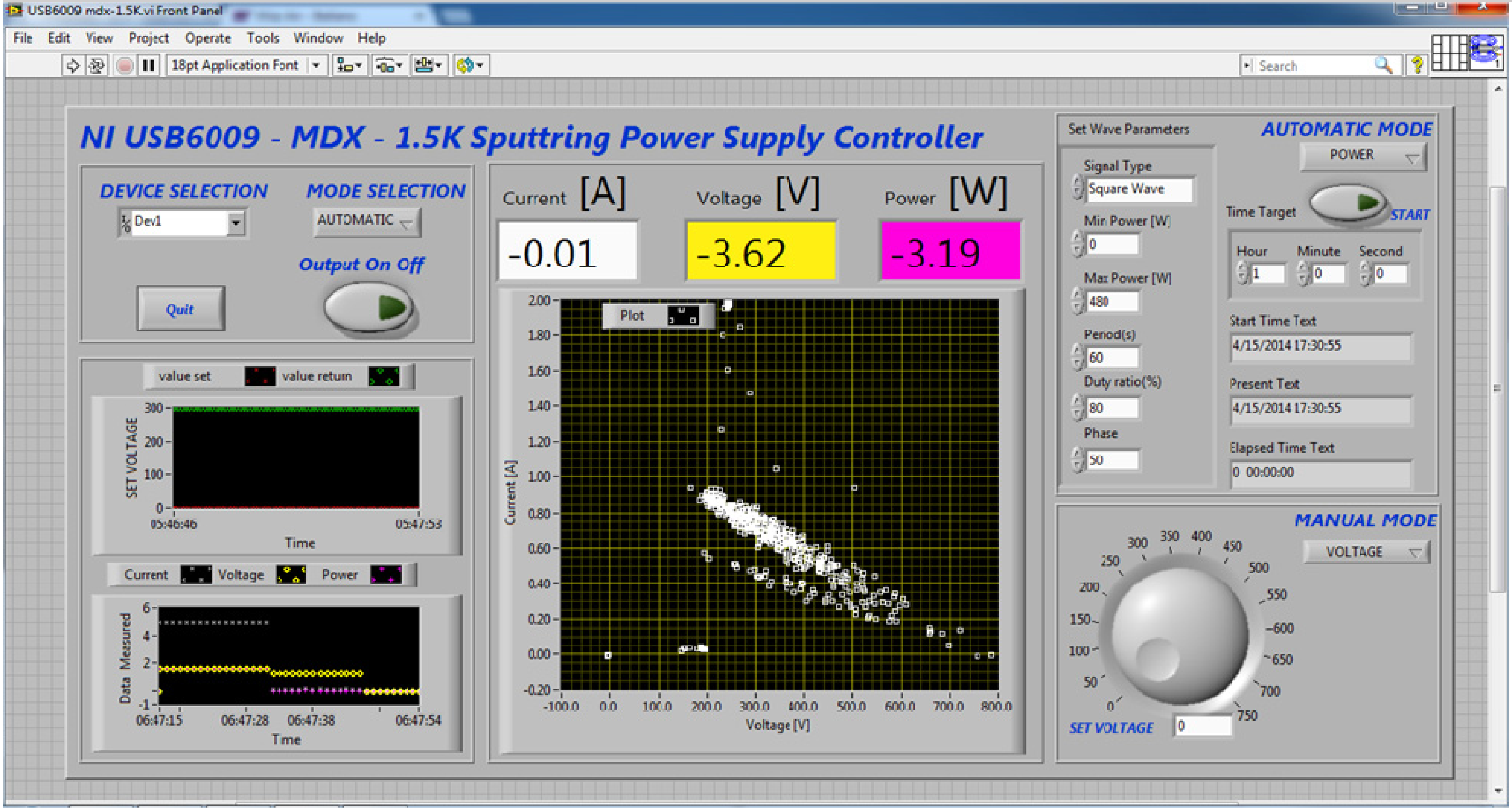
Than you deposit the new layer on the old one,

and so on for thousants of times .... as in ALD

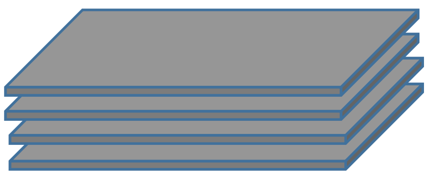
Thick film as multilayers



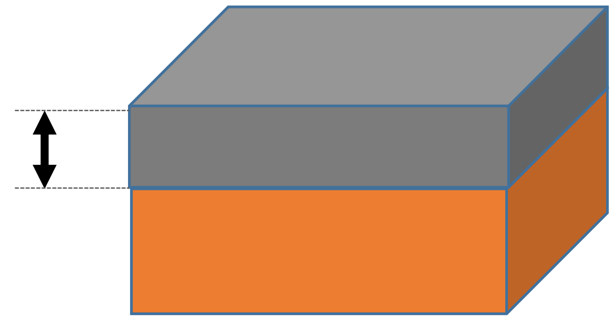
A 70 micron film is made of 350 layers of 200 nanometers



Multilayer deposition Parameters

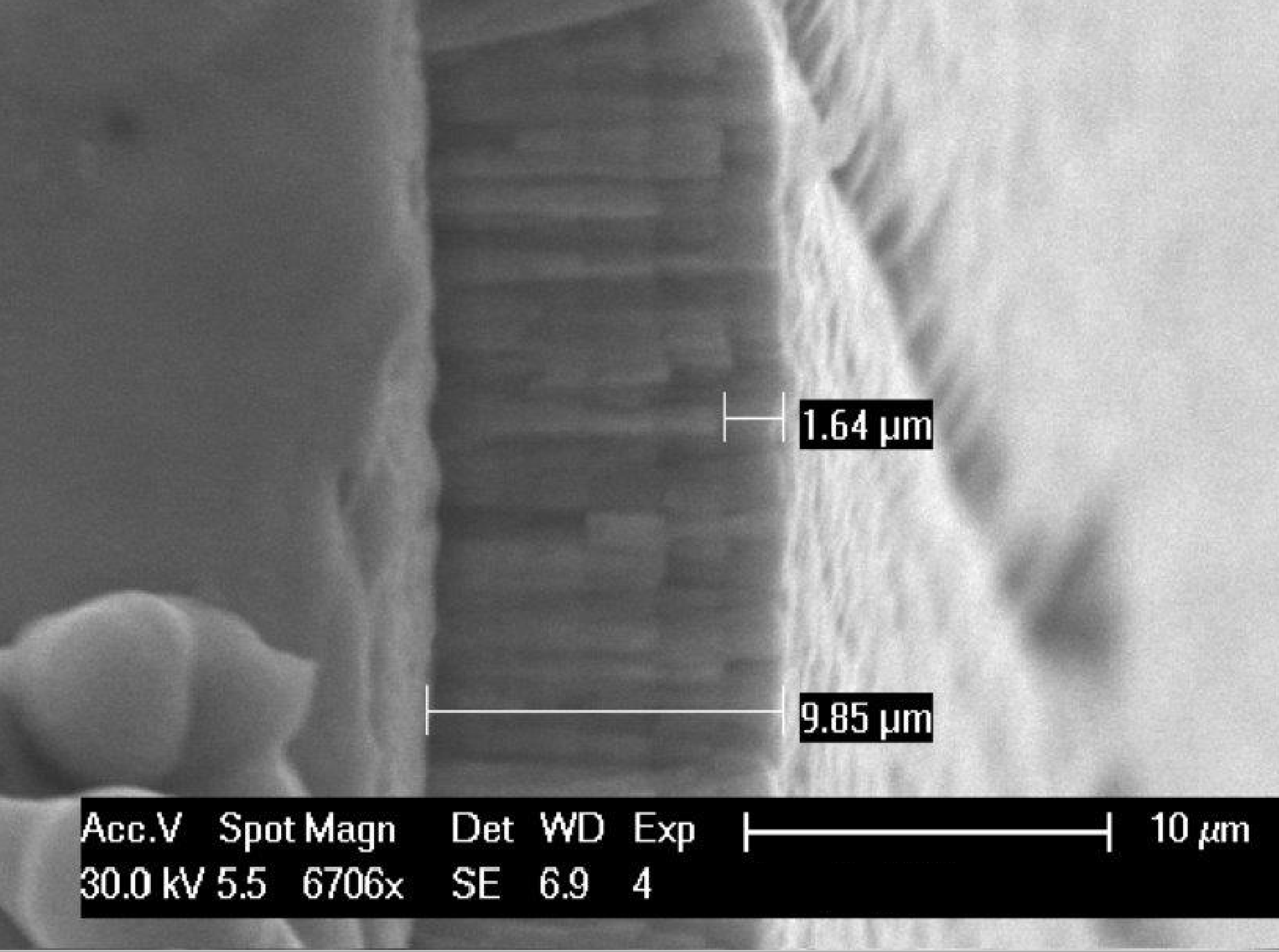


Single Layer Thickness = **100, 300, 400, 500 nm**

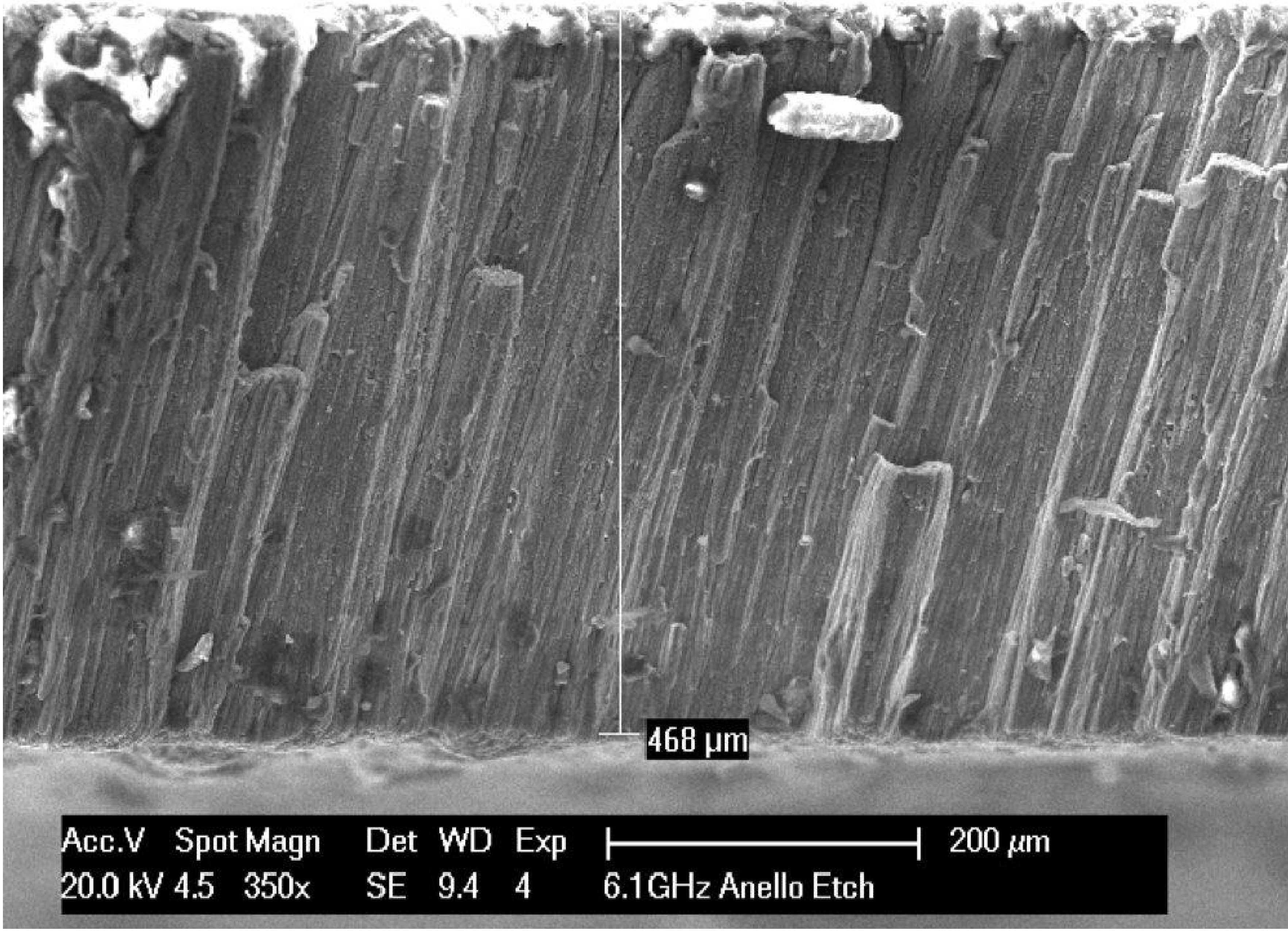


Total Thickness (on the cell) = **70 μm**

Deposition Rate = **3 nm/s**



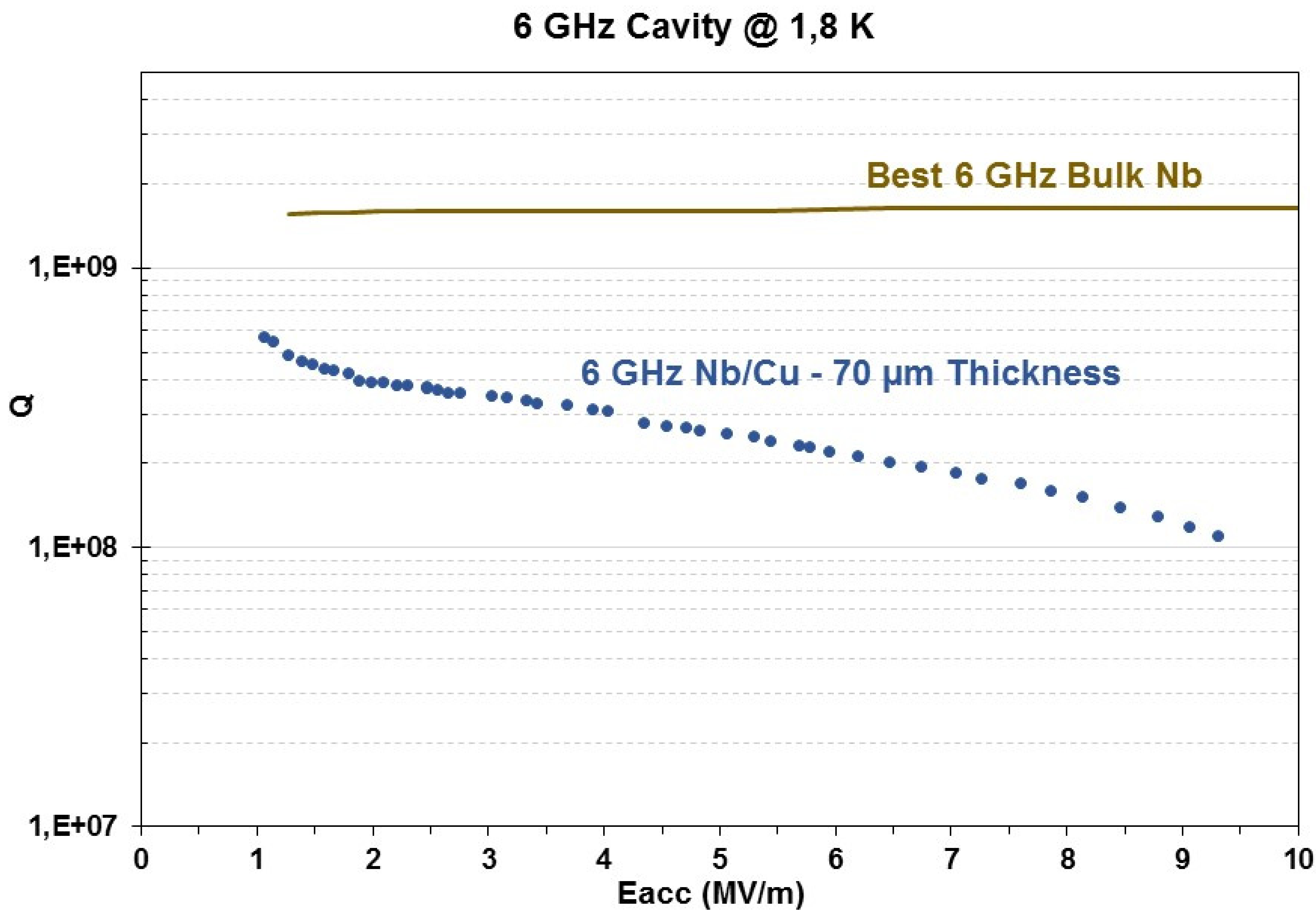
1.64 µm
9.85 µm
Acc.V Spot Magn Det WD Exp
30.0 kV 5.5 6706x SE 6.9 4
10 µm


468 µm
Acc.V Spot Magn Det WD Exp
20.0 kV 4.5 350x SE 9.4 4
200 µm
6.1GHz Anello Etch

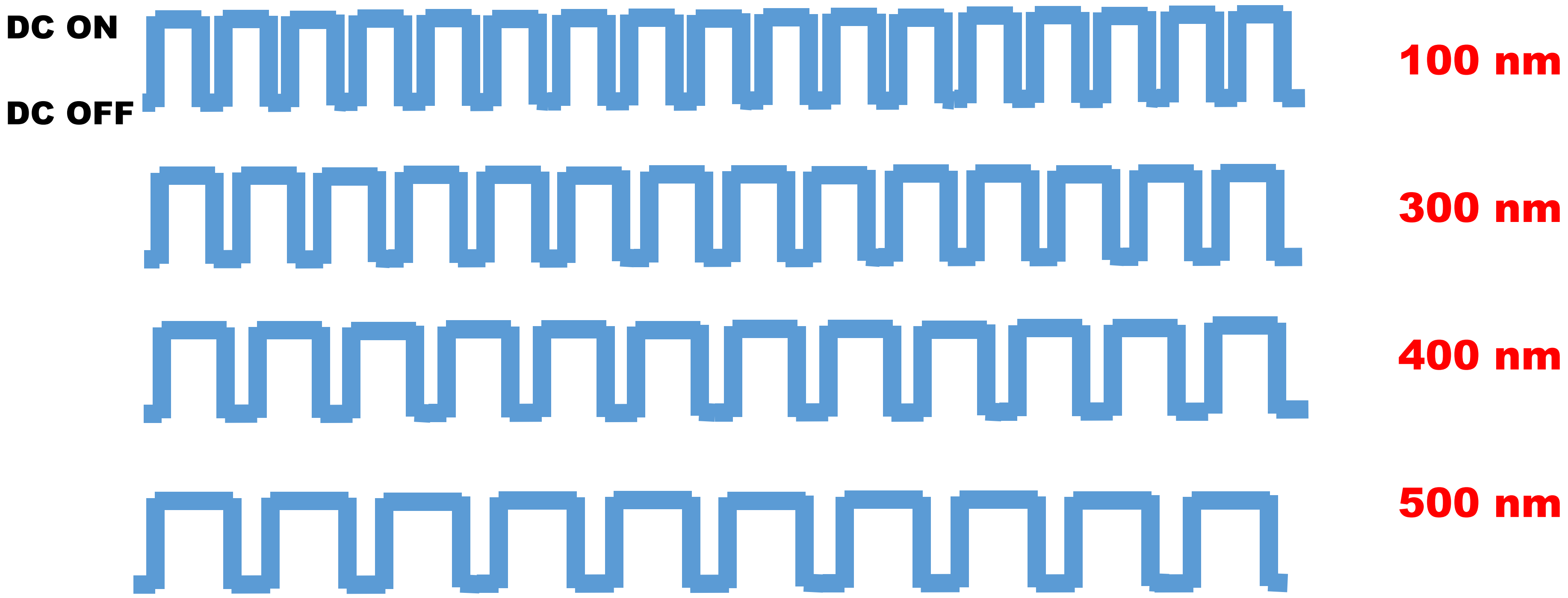
Last film sputtered was 1,2 mm thick!!!

Part 3

Experimental results on 6 GHz cavities


6 GHz Cavity @ 1,8 K
Best 6 GHz Bulk Nb
6 GHz Nb/Cu - 70 µm Thickness
Q
1,E+09
1,E+08
1,E+07
0
1
2
3
4
5
6
7
8
9
10
Eacc (MV/m)

Deposition of several cavities, by modulating the thickness of single layer



Total thickness of all cavities is kept constant to 70 μm

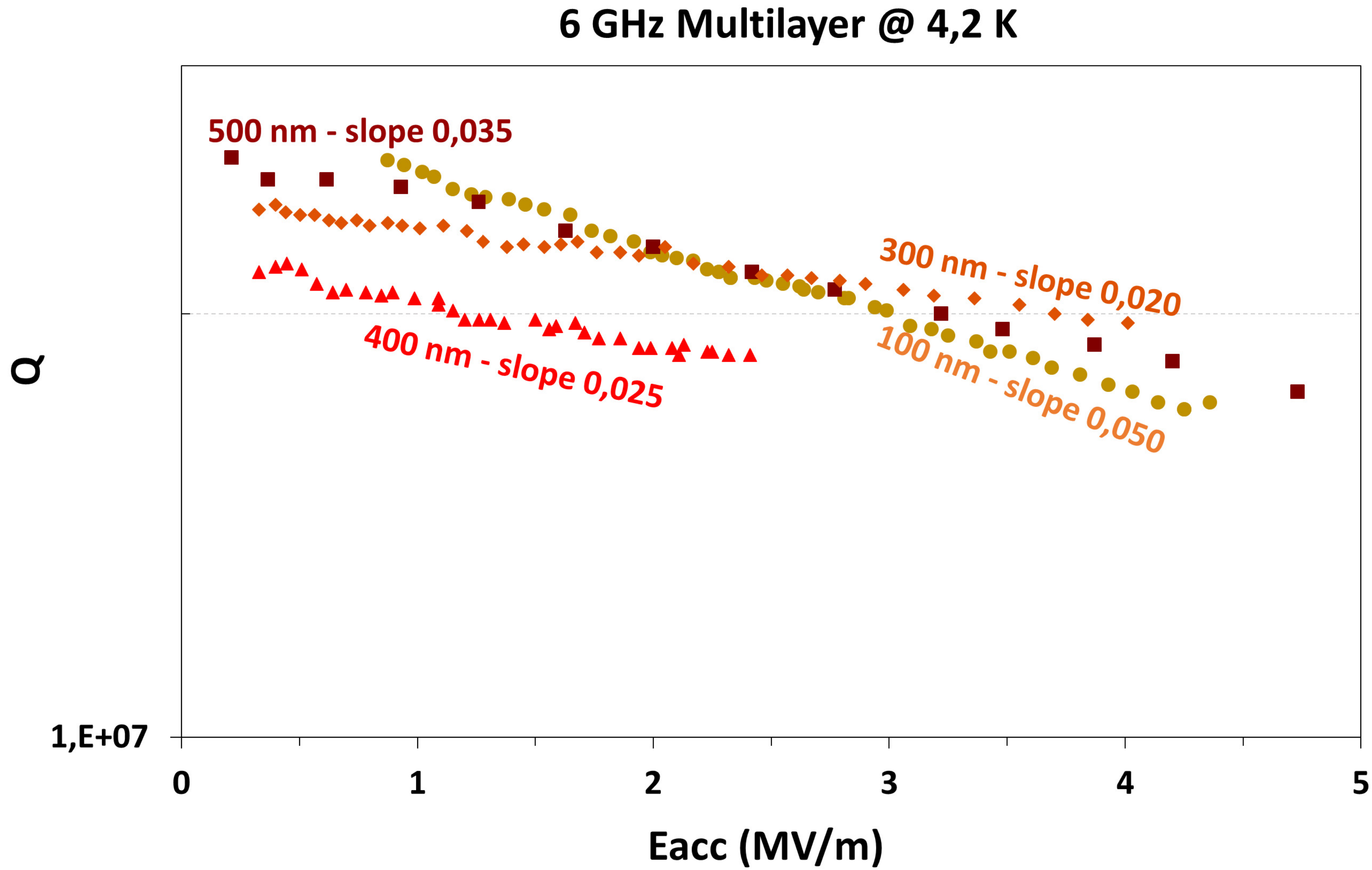
A key parameter: the single layer thickness

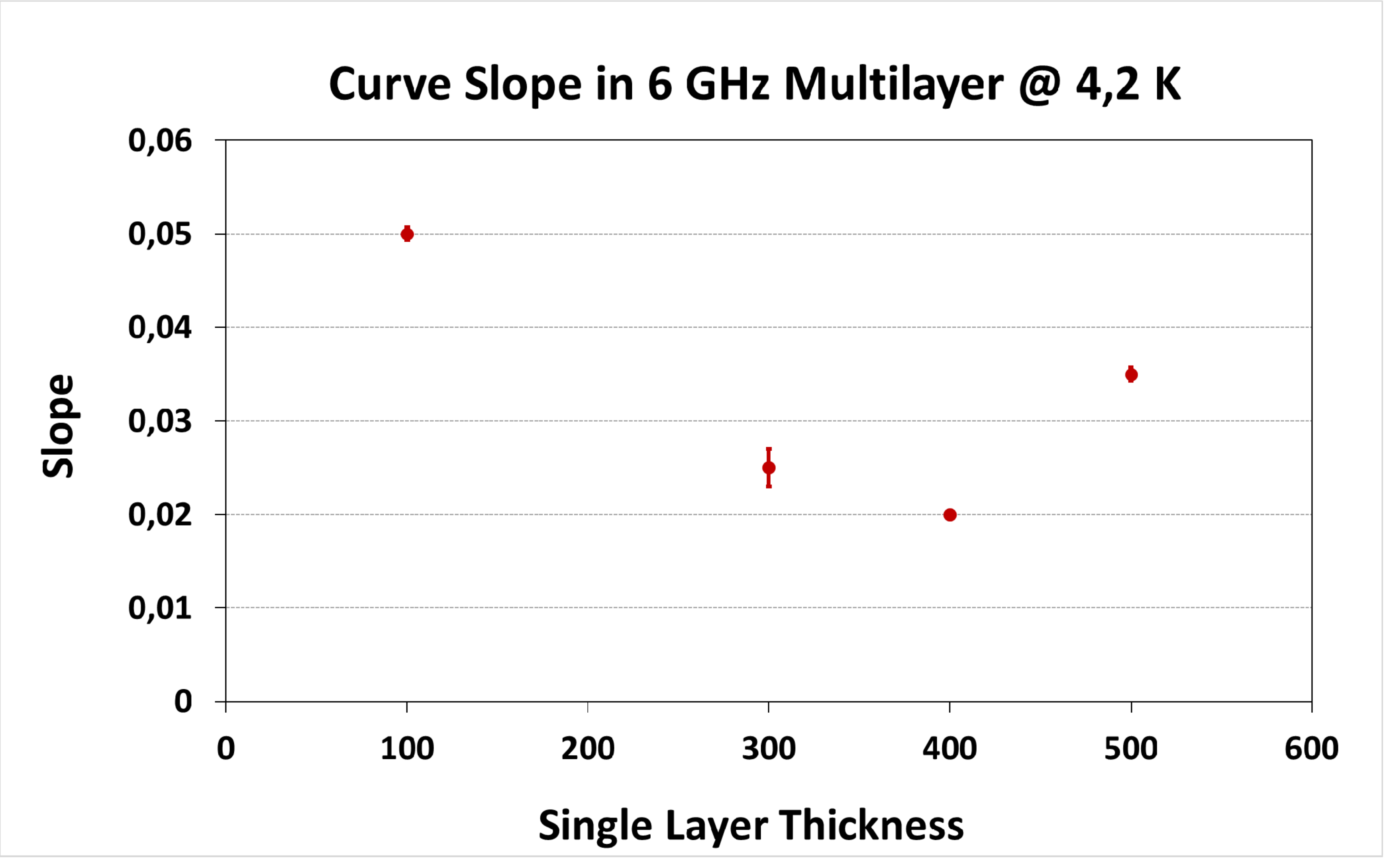
The single layer cannot be too thin,

because: T_c and RRR increase with thickness

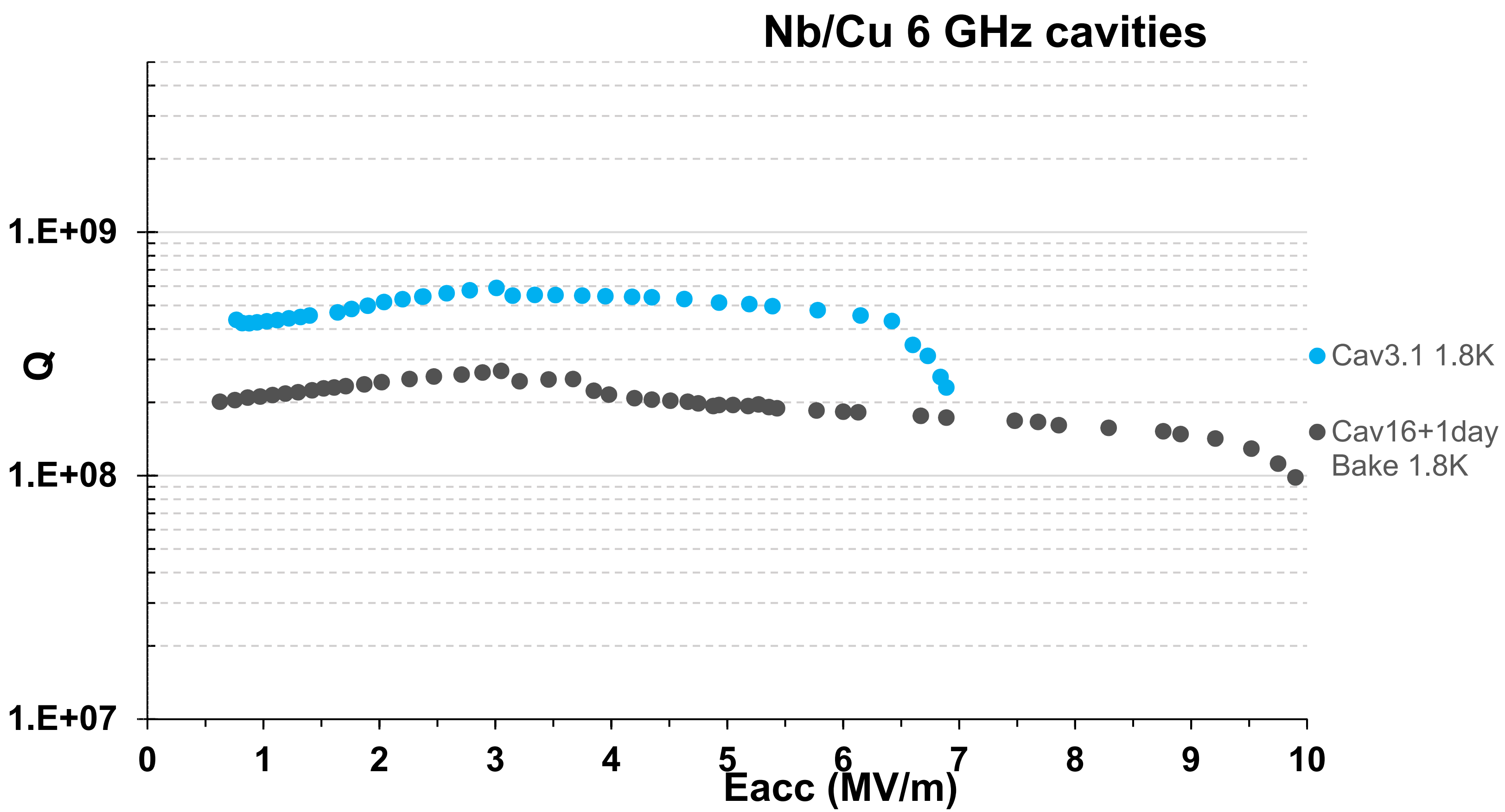
The single layer cannot be too large,

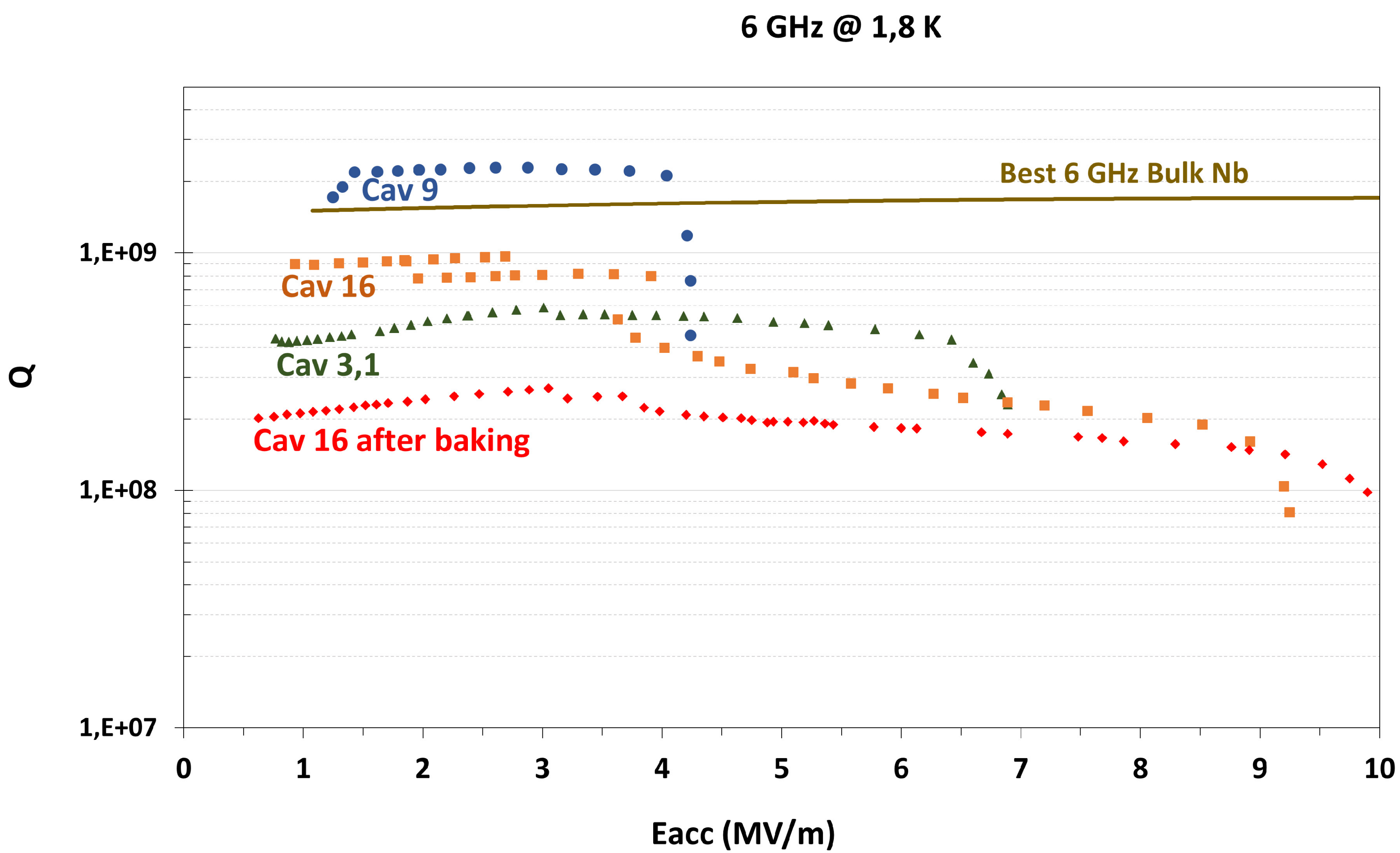
because: Stress will increase with thickness


6 GHz Multilayer @ 4,2 K
500 nm - slope 0,035
300 nm - slope 0,020
400 nm - slope 0,025
100 nm - slope 0,050
Q
1,E+07
0
1
2
3
4
5
Eacc (MV/m)



Curve Slope in 6 GHz Multilayer @ 4,2 K
Slope
0,06
0,05
0,04
0,03
0,02
0,01
0
0
100
200
300
400
500
600
Single Layer Thickness


Nb/Cu 6 GHz cavities
1.E+09
1.E+08
1.E+07
Q
0
1
2
3
4
5
6
7
8
9
10
Eacc (MV/m)
Cav3.1 1.8K
Cav16+1day
Bake 1.8K


6 GHz @ 1,8 K
Best 6 GHz Bulk Nb
Cav 9
Cav 16
Cav 3,1
Cav 16 after baking
1,E+09
1,E+08
1,E+07
Q
0
1
2
3
4
5
6
7
8
9
10
Eacc (MV/m)

In the R&D for flat-Q cavities,

Thick films are not the arrival point,

but just the way!

道

Once optimized thick films,

the way will consist in reducing the thickness,

in order to arrive to deposit again

as thin as possible films


The 8th International Workshop on:
THIN FILMS AND NEW IDEAS FOR PUSHING THE LIMITS OF RF SUPERCONDUCTIVITY
October 8 - 10, 2018
Legnaro National Laboratories – INFN (Padua) ITALY