# Progress with Nb/Cu film engineering with energetic condensation

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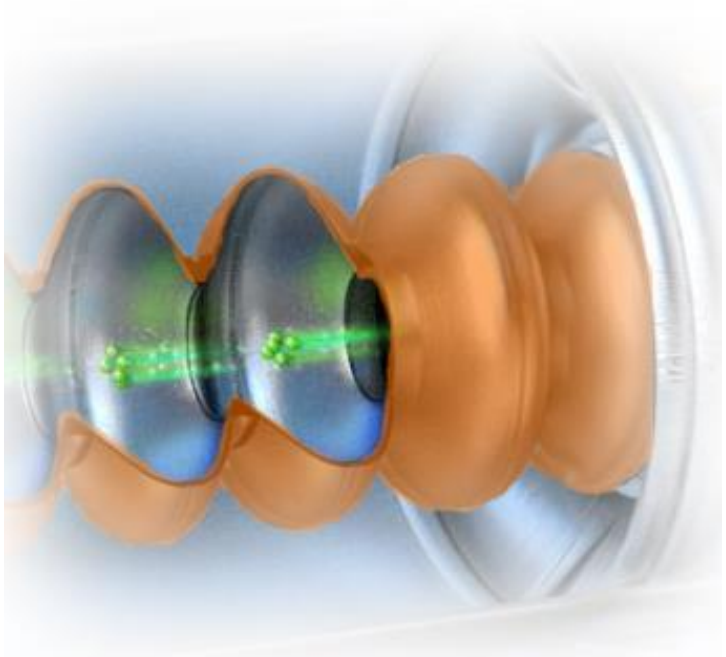

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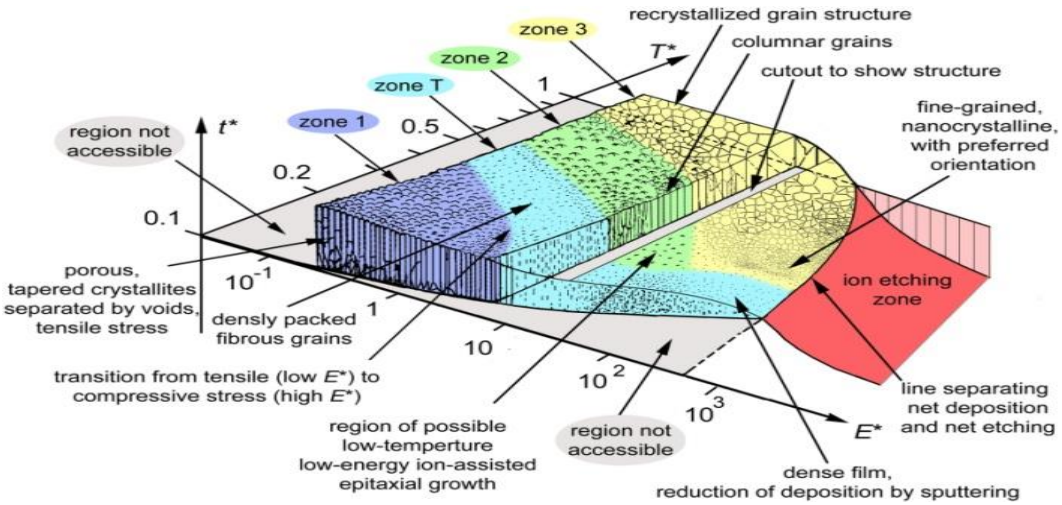
# OUTLINE

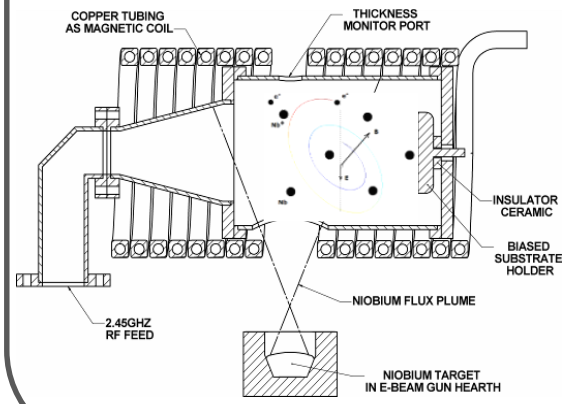
- Introduction
- ECR Nb/Cu film structure
- RF Behavior of ECR Nb/Cu measured by QPR
- Conclusion

# Energetic Condensation via ECR




Anders, André. "A structure zone diagram including plasma-based deposition and ion etching." *Thin Solid Films* 518.15 (2010): 4087-4090.

## Electron Cyclotron Resonance (ECR)




No working gas

**Singly charged ions (64eV)**

**produced in vacuum**

**Controllable deposition energy with Bias voltage**

Excellent bonding

No macro particles

## High Power Impulse Magnetron Sputtering (HiPIMS)

Requires working gas

**Mulitply charged ions of Nb & Kr**

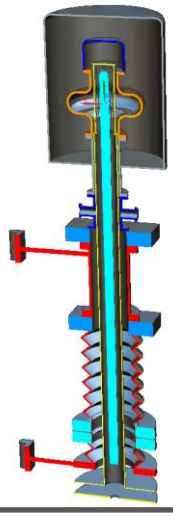
**Presence of neutrals**

**Controllable deposition energy with Bias voltage**

Excellent bonding

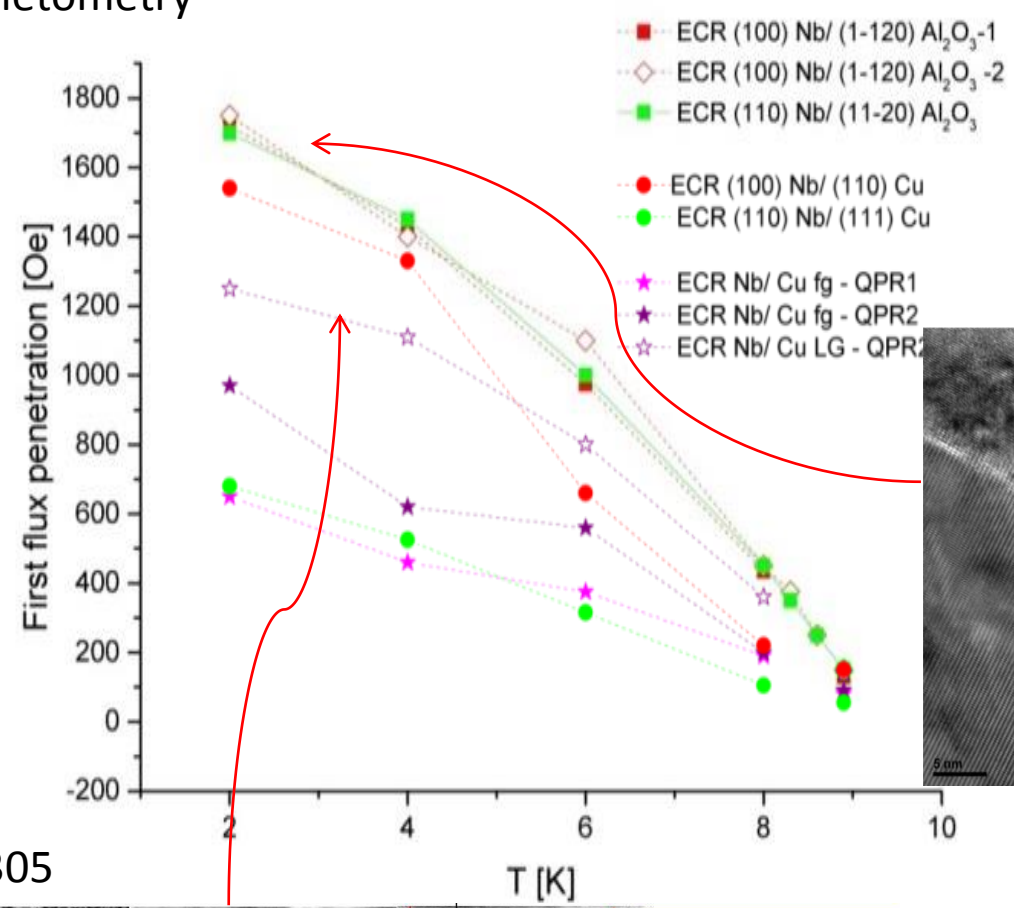
No macro particles

Ease of cavity configuration

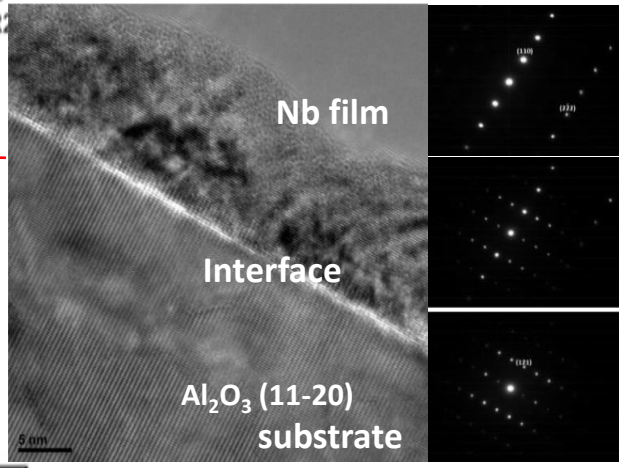


# ECR Nb film properties

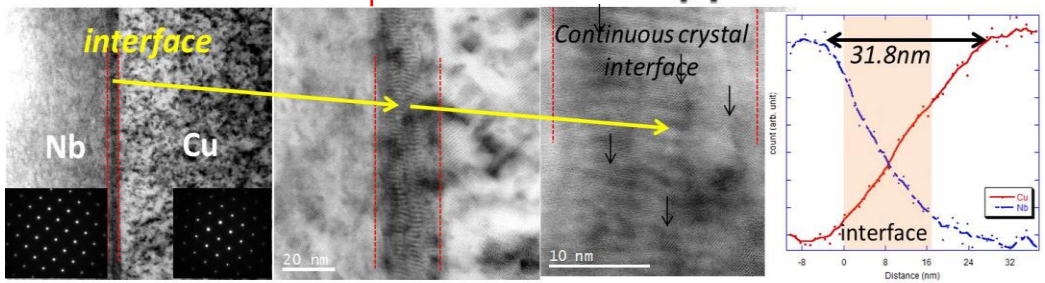
DC SQUID Magnetometry




RRR 725




RRR 305




***Full control of interface for enhanced adhesion***

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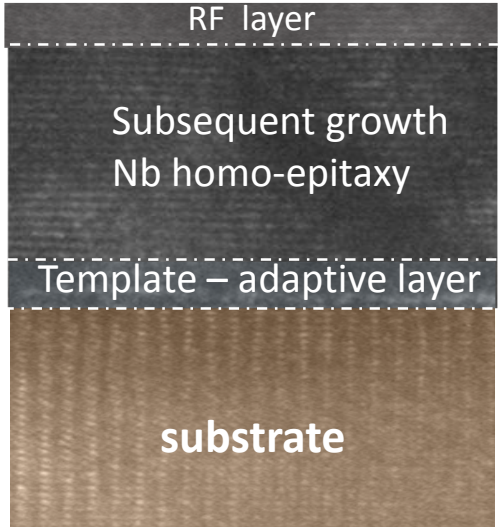
# Energetic Condensation via ECR

## Energetic Condensation

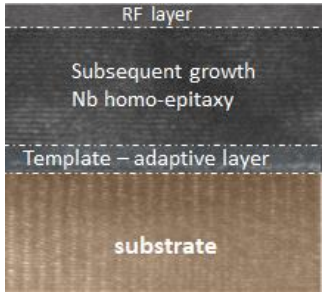
**Sequential phases for film growth**

- Interface
- Film nucleation
- Growth of appropriate template for subsequent deposition
- Deposition of final surface optimized for minimum defect density.

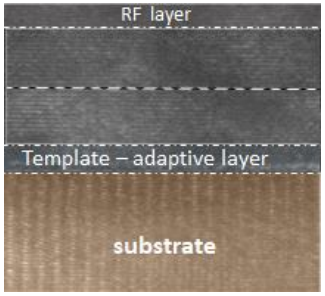



## Opportunity for film engineering

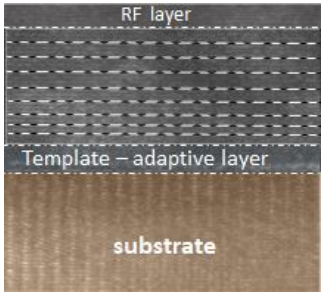
Continuous



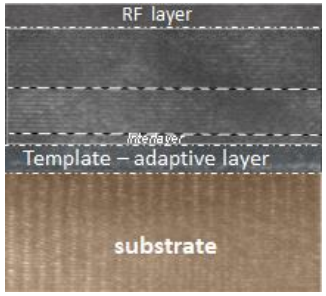

Interrupted



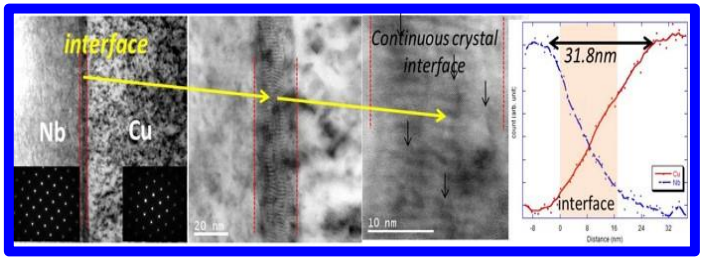

Interrupted multiple steps




Interlayer/Interrupted

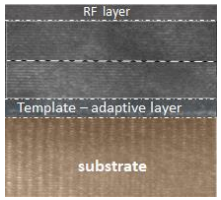


# Nb Film Structure Engineering




Nb/Cu

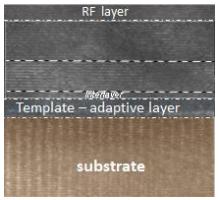
360 °C

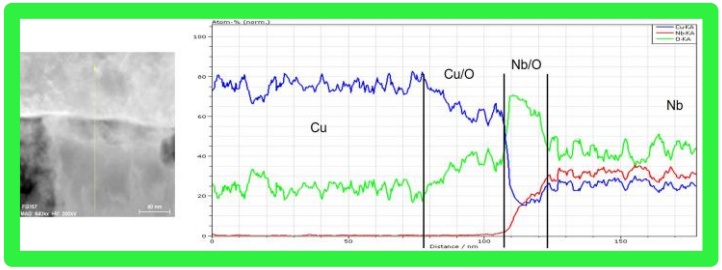



200 °C

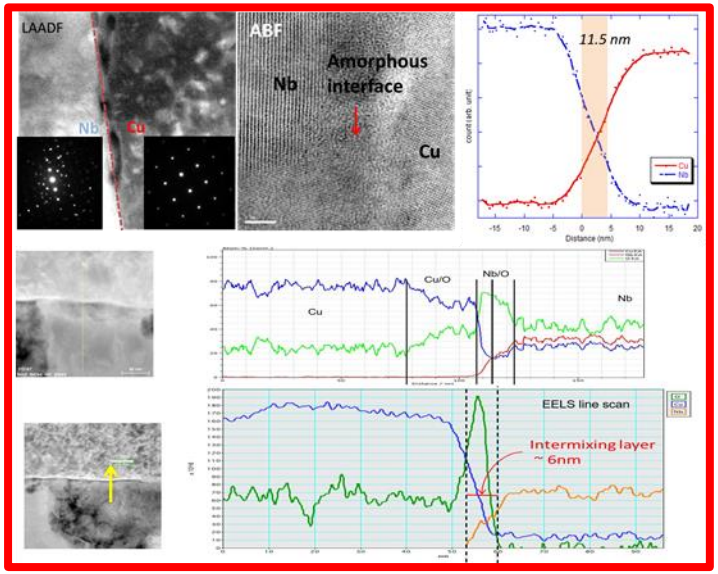
Nb/CuO

Nucleation 184 eV
Subsequent growth 64 eV



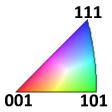




$Nb/Nb_2O_5/Cu$

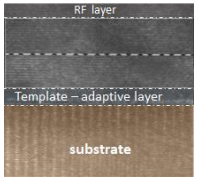


# Nb film engineering - Hetero-epitaxy at 360°C

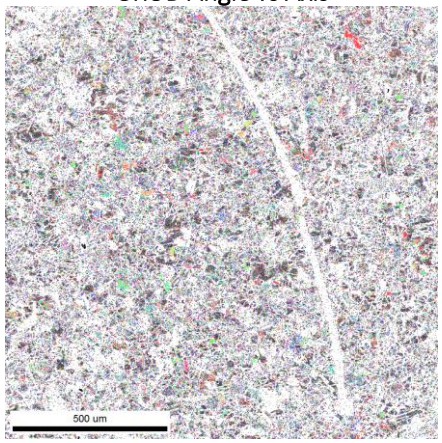
## Nucleation @ 184 eV + subsequent growth @ 64 eV in 2 steps



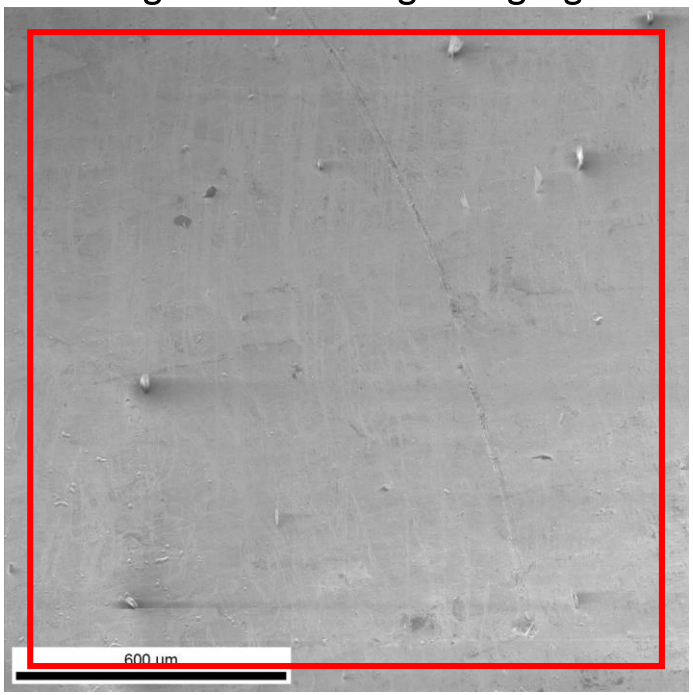

IPF Map+Cl 0.1




GROD Angle vs Axis

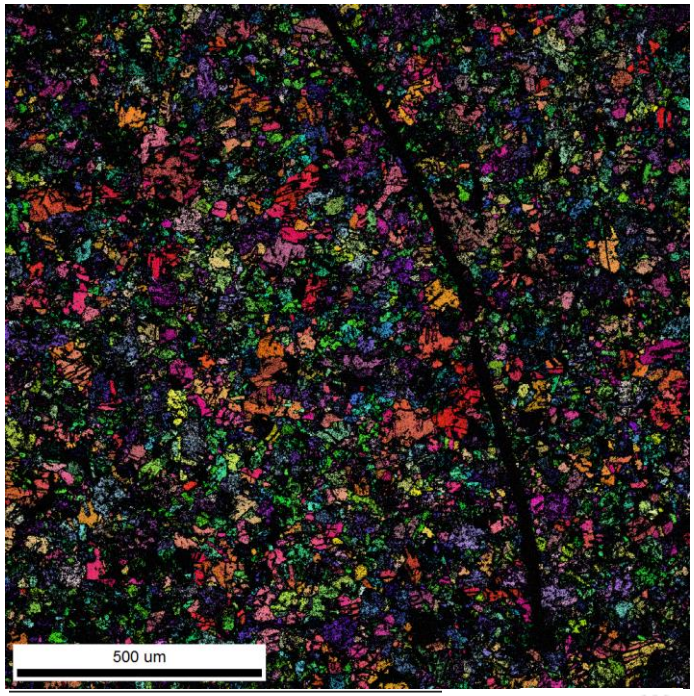


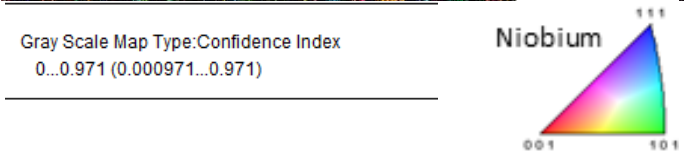

SE Image with EBSD Region Highlighted



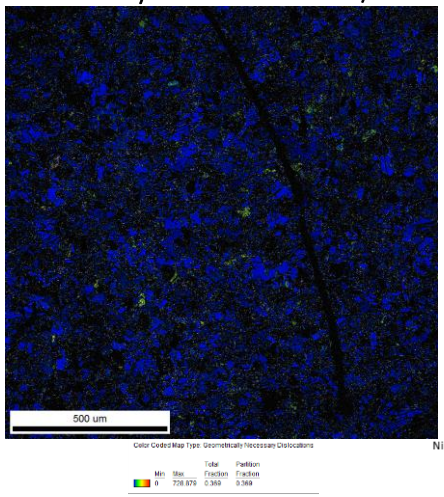

1500 µm

IPF w Cl of 0.1




Geometrically Nec Dislocations w/ Cl of 0.1

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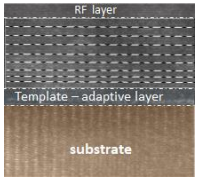
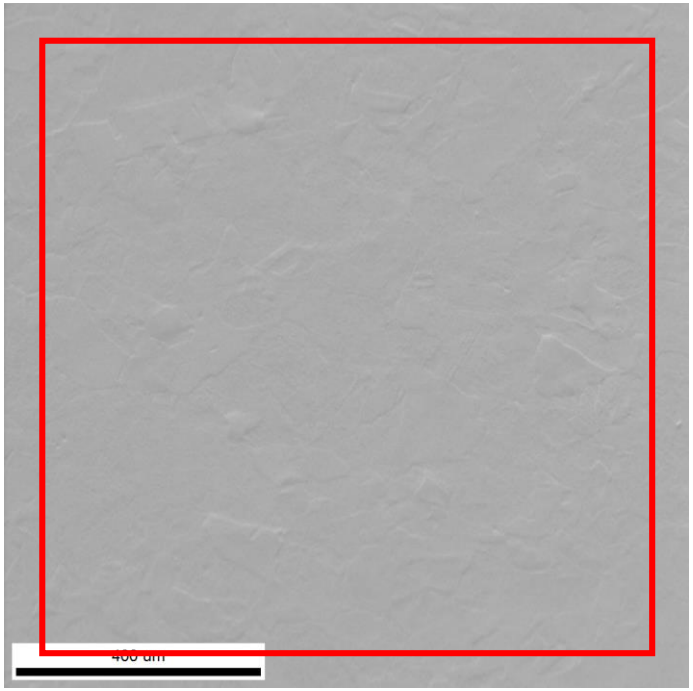
# Nb film engineering- Altered hetero-epitaxy at 360°C

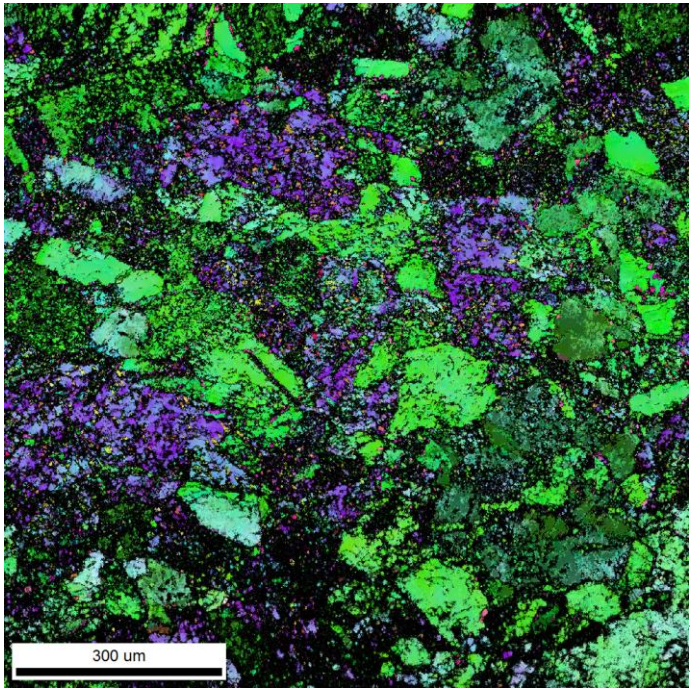
## Nucleation @ 184 eV + subsequent growth @ 64 eV in 10 steps

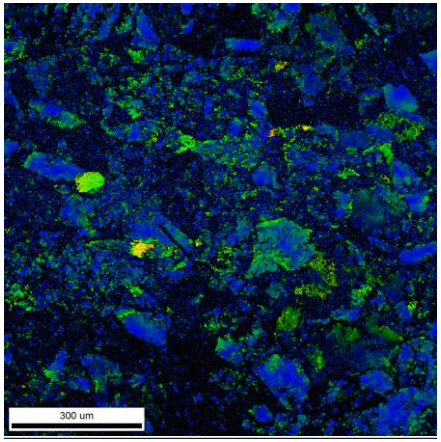

IPF Map+CI 0.1



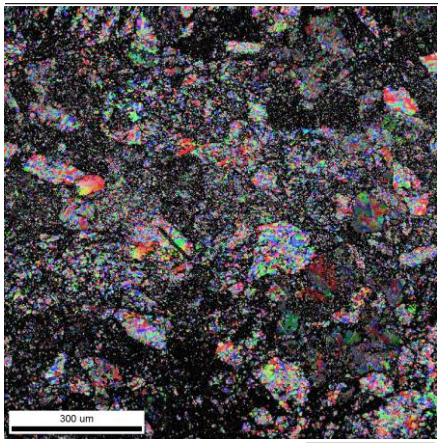

1.5 mm




Color Coded Map Type: Grain Reference Orientation Deviation - Angle

| | Min | Max | Total Fraction | Partition Fraction |
|---|---|---|---|---|
| | 0 | 42.5711 | 0.750 | 0.750 |




Niobium


Boundaries: <none>

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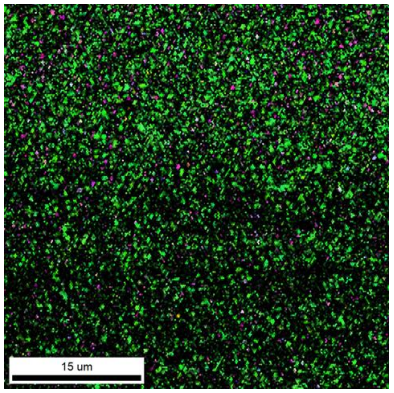
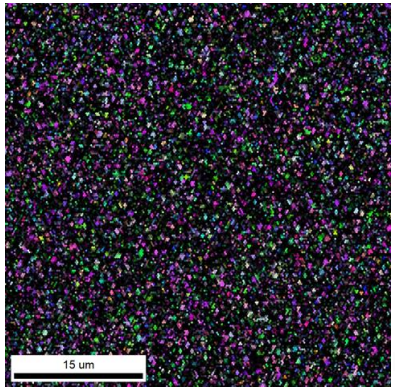
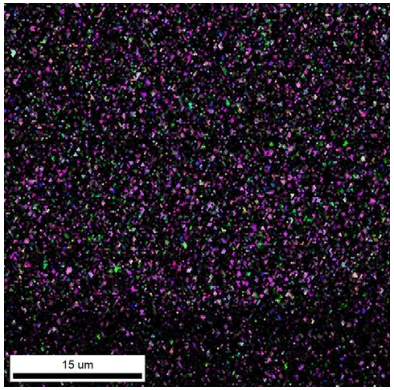
# Nucleation + 10 sequential coating : influence of energy

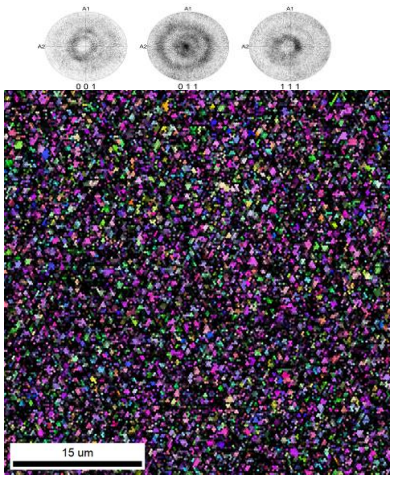

IPF Map+CI 0.1

## 94 eV

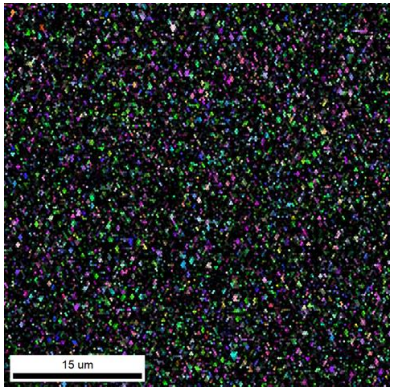


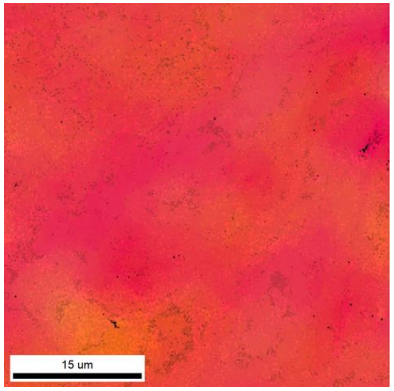



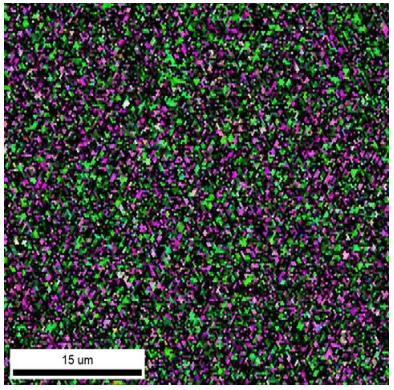



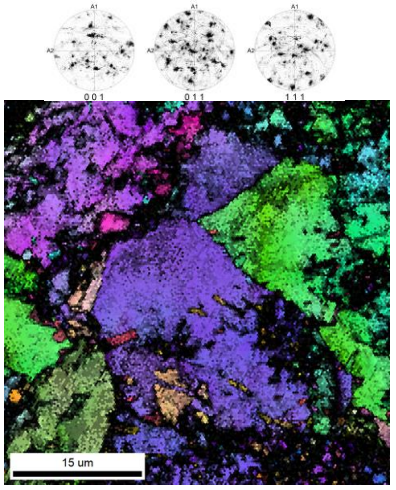




## 244 eV




Cu 100

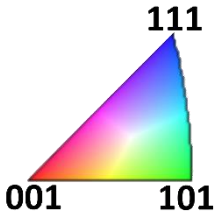
Cu 110

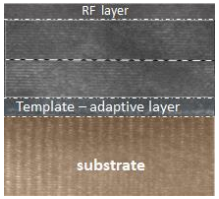
Cu 111

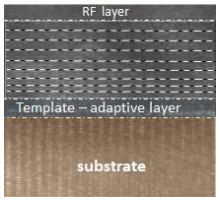
Cu fine grains

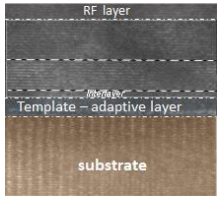
# Nb Film Engineering – Altered heteroepitaxy

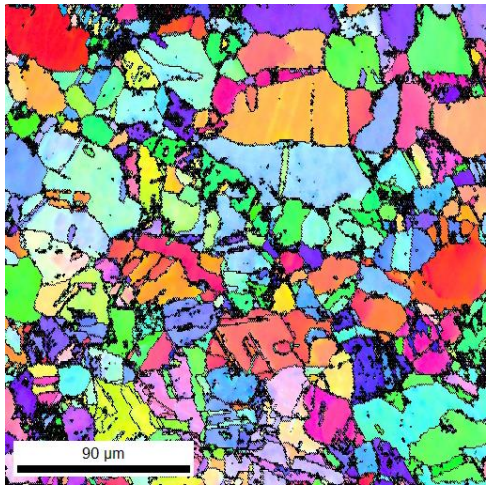
Nucleation at 184 eV , 360C

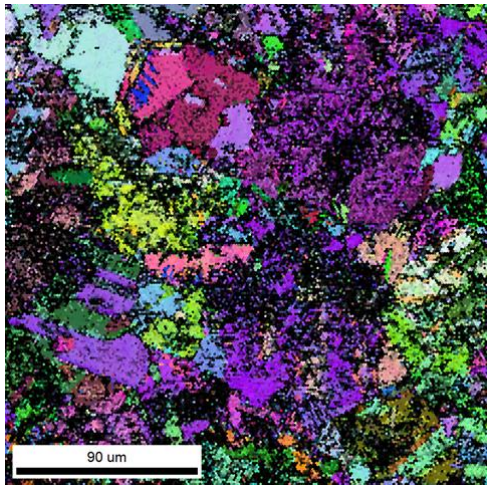


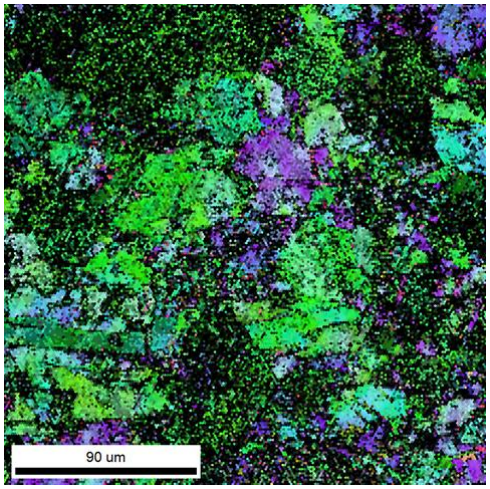



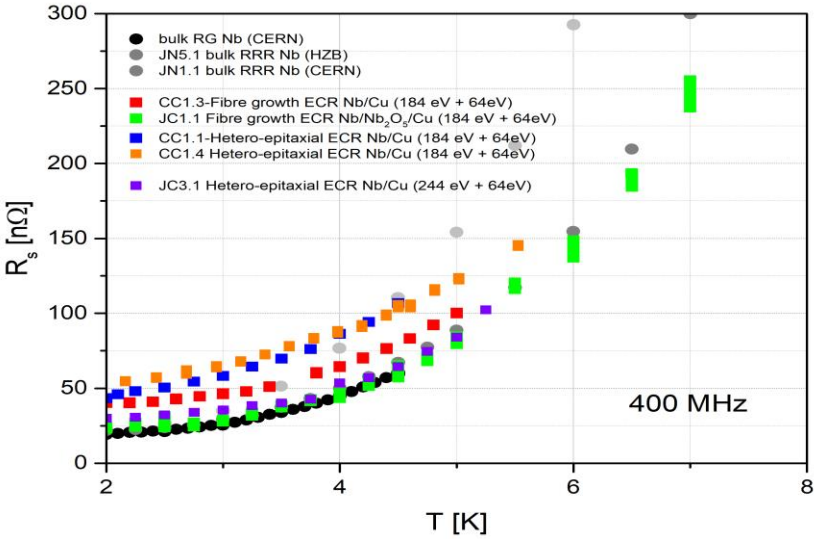



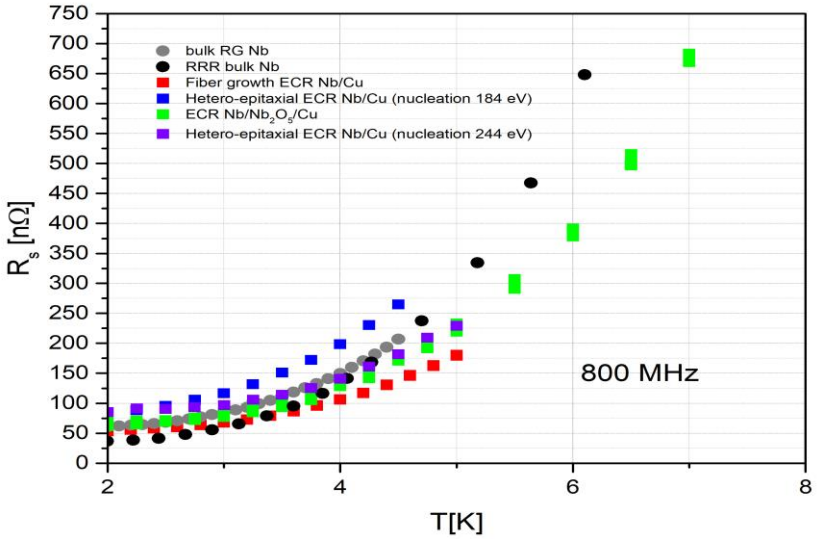

Hetero-epitaxial growth

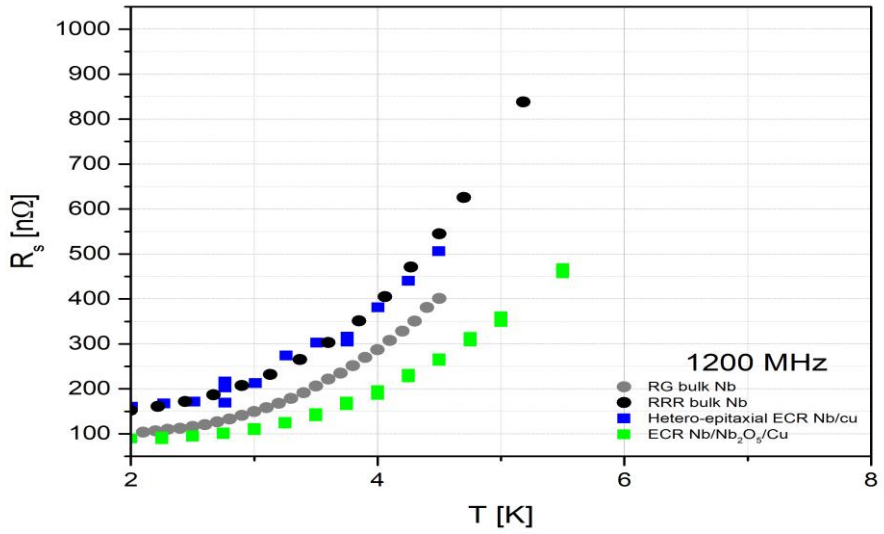
Hetero-epitaxial growth disrupted with subsequent re-nucleation?

Same large crystal size but preferentially (110)?

# ECR Nb films $R_s$ vs T



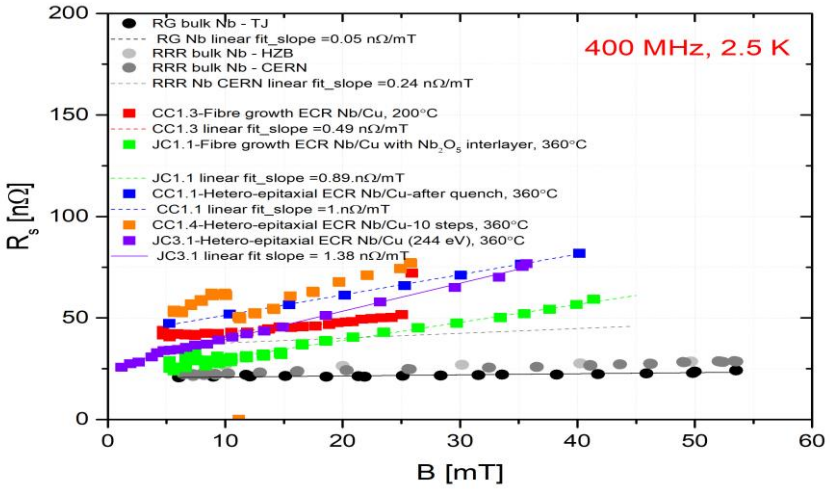



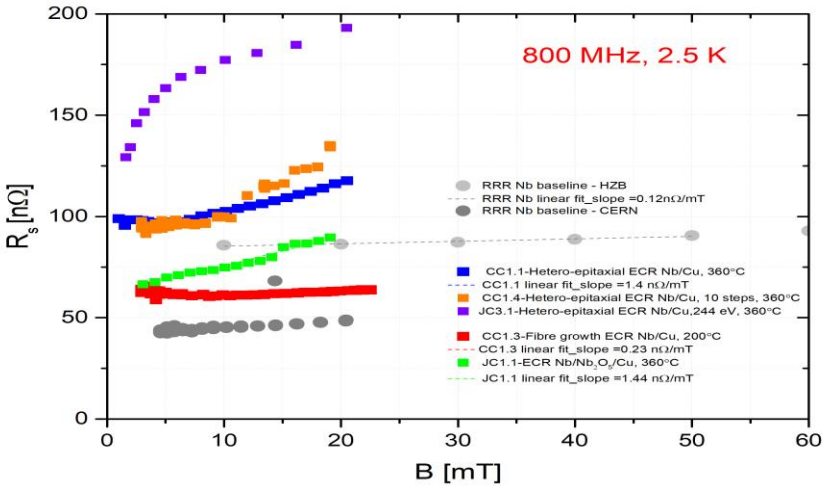



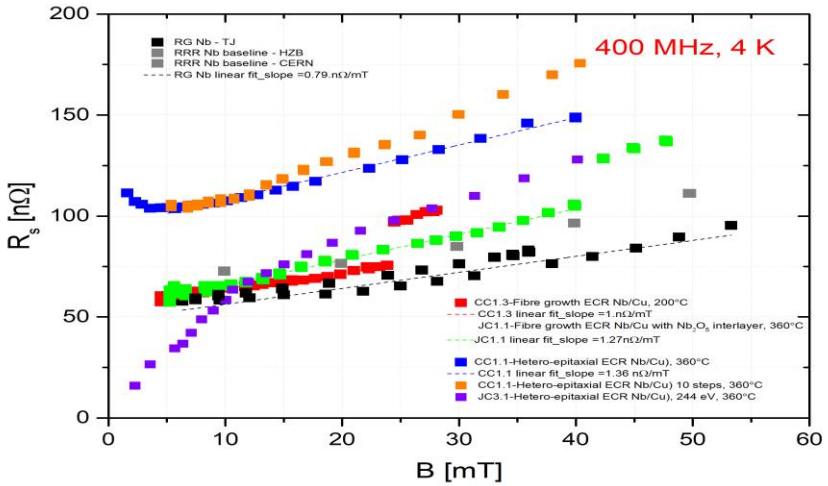

**Fiber growth ECR Nb/Cu films behave closer to bulk Nb in QPR measurements**

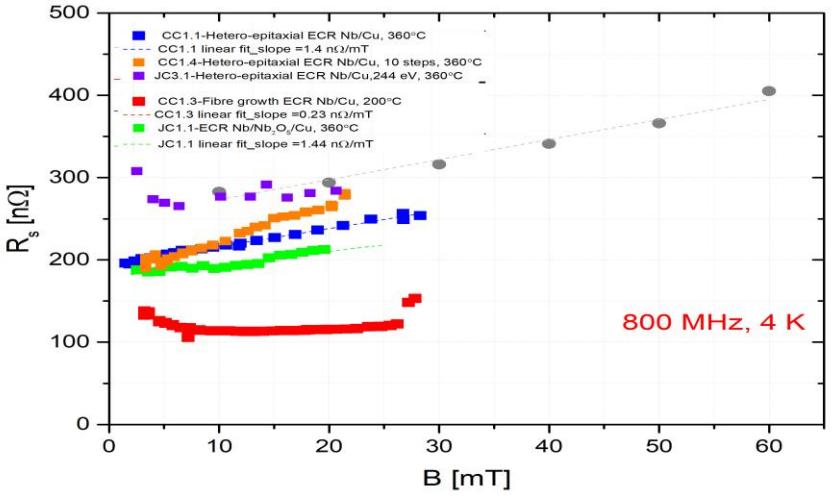
# ECR Nb/Cu Film RF Results on QPR samples

RF measurement at CERN: S. Aull, M. Arzeo, L. Vega Cid



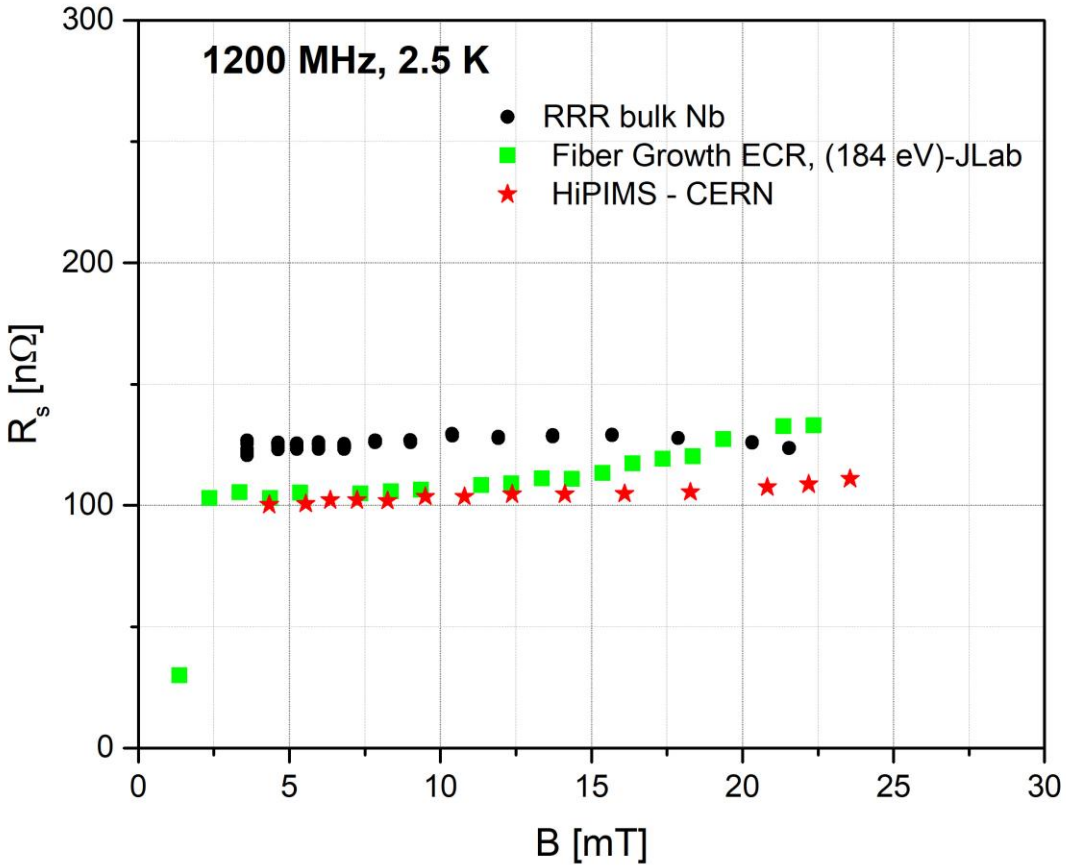




**Some ECR films show mitigation of the Q-slope**
**Insight on interface, coating temperature influence**

# ECR Nb/Cu Film RF Results on QPR samples

RF measurement at CERN: S. Aull, M. Arzeo, L. Vega Cid

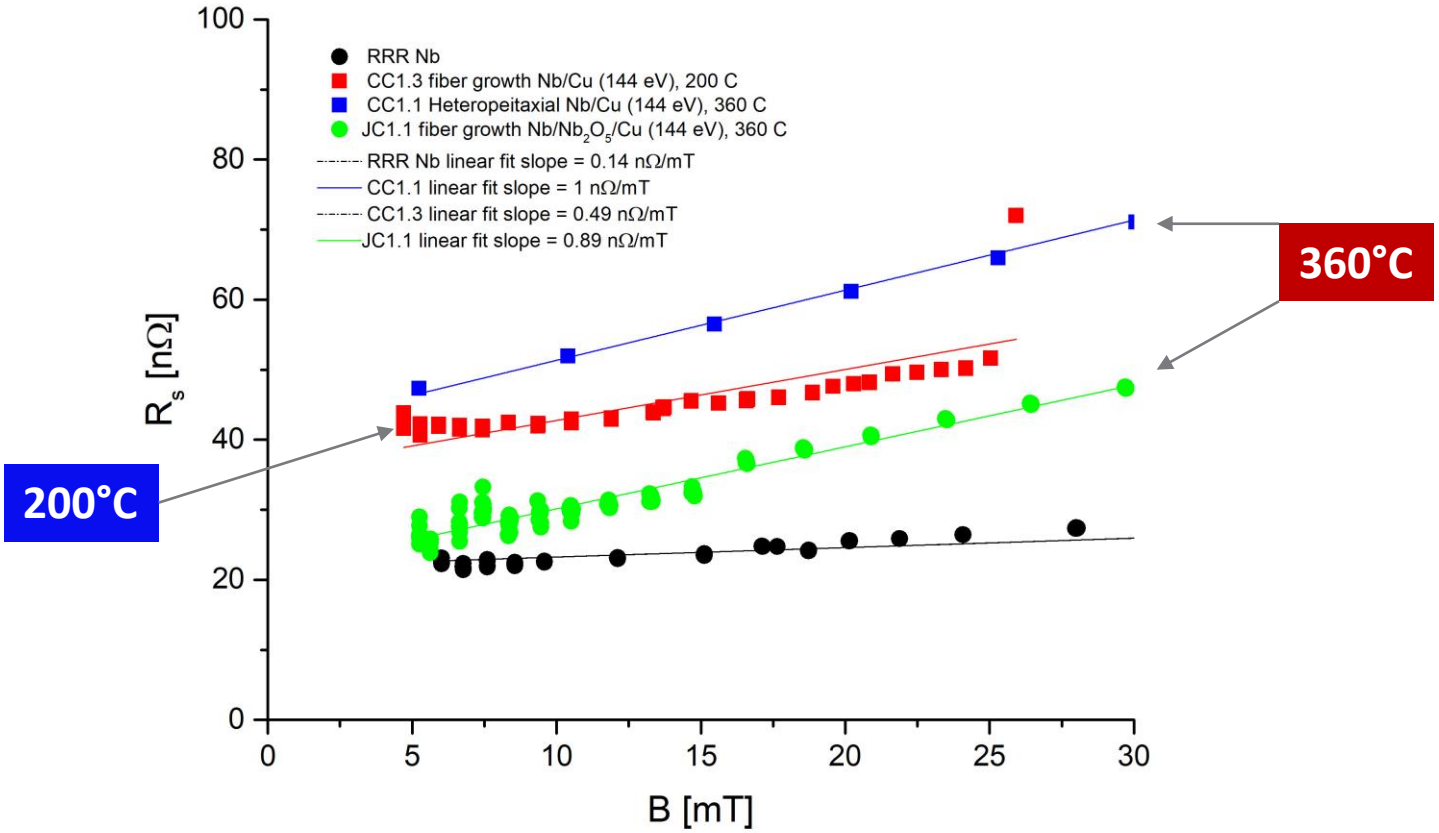



**Energetic Condensation Nb/Cu films show similar RF behavior compare to bulk Nb in QPR measurments**

# ECR Nb/Cu Film – Fiber Growth vs. Hetero-epitaxy

RF measurement at CERN: S. Aull, M. Arzeo, L. Vega Cid

400 MHz, 2.5 K



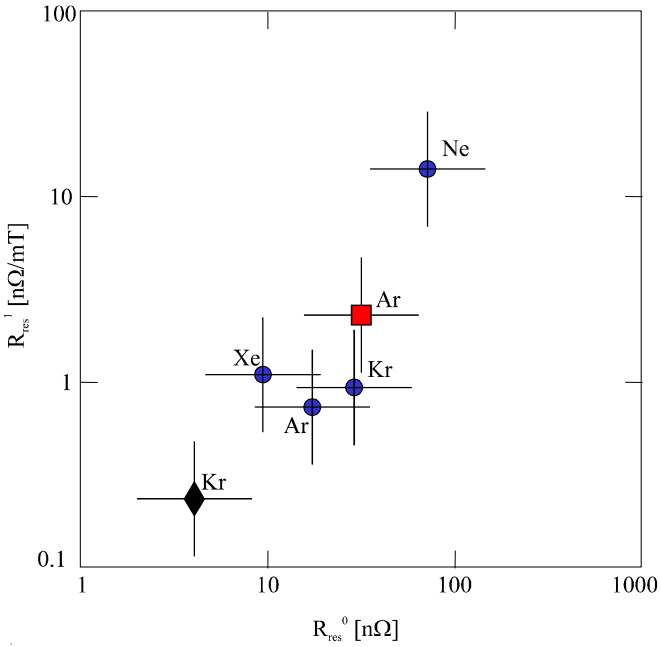

**Fiber growth ECR Nb/Cu show better mitigation trend of the Q-slope**
**Insight on interface, coating temperature influence**

# CONCLUSION

- Several “knobs to turn” to tune Nb film structure and superconducting prorperties
- Mitigation of Q-slope for energetic condensation films

- **ECR fiber growth films thus far seem better performing than hetero-epitaxial films. Also observed for HiPIMS Nb/Cu (cf. F. Avino’s talk)**

**cf. CERN DC magnetron sputtering studies**

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- Establish adequate process controls
- **Need better substrates and chemical processes**
- Need more RF measurements statistics