DC Field Emission Results on Nb Samples

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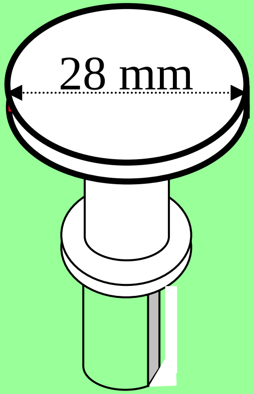
- **Overview of Nb samples investigated since last meeting**
- **Surface characterization of single/large crystal samples**
- **Suppression of FE by DIC and nature of emitters**
- **Emitter statistics of single/large crystals after BCP/HPR**
- **Correlation between FE onset field and defect size**
- **First results on SC/LG after in-situ bakeout at 150°C**
- **Intrinsic FE of SCNb in defect-free sample areas**
- **Conclusions and outlook for FP7**

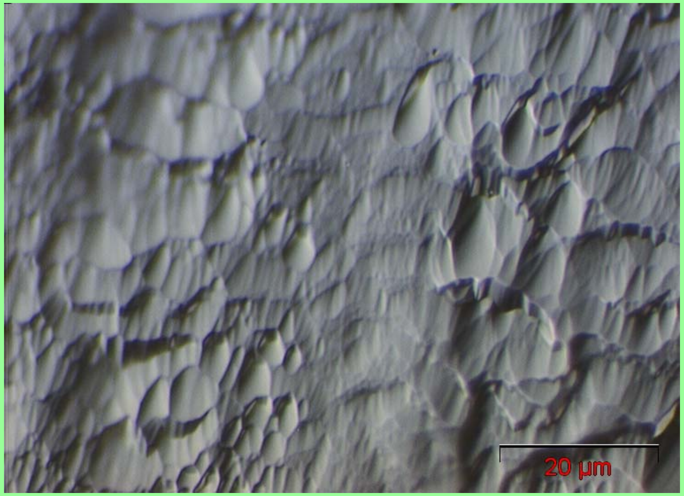
Overview of Nb samples investigated since last meeting

Focus on large grains (LG) and single crystals (SC) between November 06 and July 07

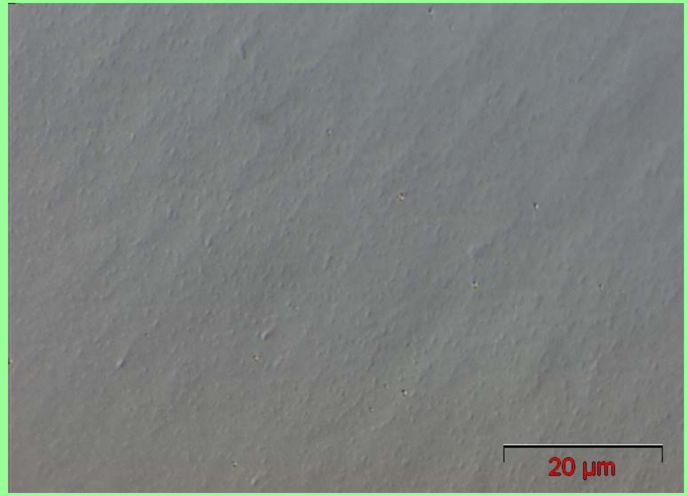
Sample #	Polishing in µm	HPR	FESM	SEM/ EDX	DIC	FESM	SEM/ EDX
PolyNb	EP at Henkel	yes	yes	yes	no	no	no
LGNb1	BCP30	yes	yes	yes	yes	yes	yes
LGNb2	BCP30	yes	yes	yes	yes	yes	yes
LGNb3	BCP100	yes	yes	yes	no	no	no
SCNb1	BCP30	yes	yes	yes	yes	yes	yes
SCNb2	BCP30	yes	yes	yes	yes	yes	yes
SCNb3	BCP100	yes	yes	yes	no	no	no
SCNb4	BCP100	yes	yes	yes	no	no	no
SCNb7	BCP100	yes	yes	yes	no	no	no



Optical microscope images of SC and LG Nb samples



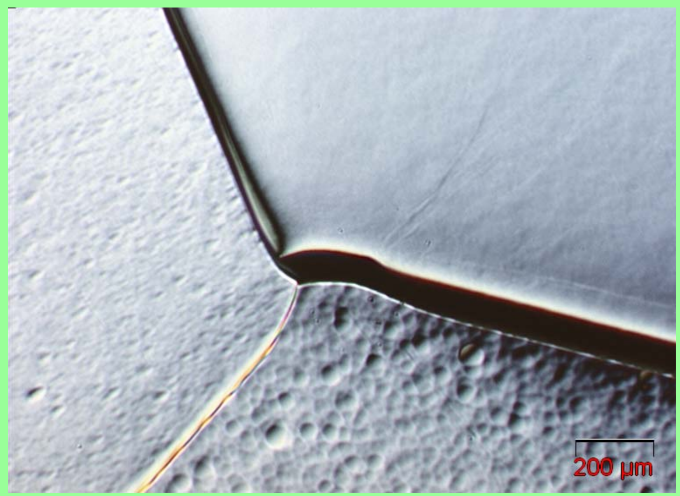
SCNb1 – BCP 30 µm



SCNb2 – BCP 30 µm

measured by
X. Singer
at DESY

SCNb7 – BCP 100 µm

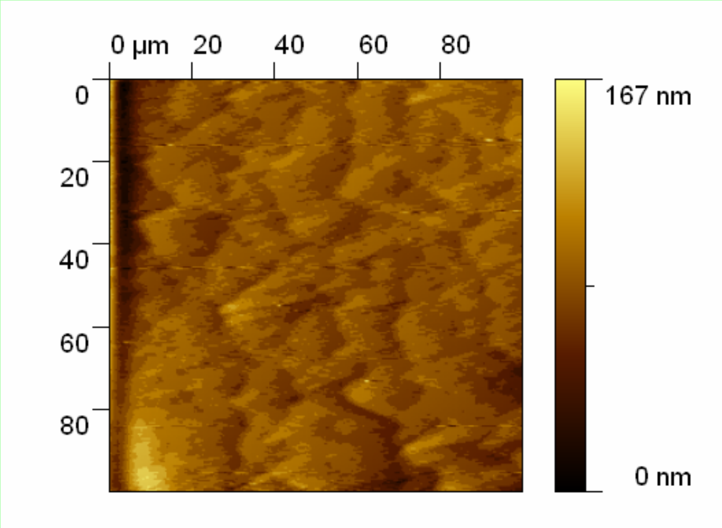


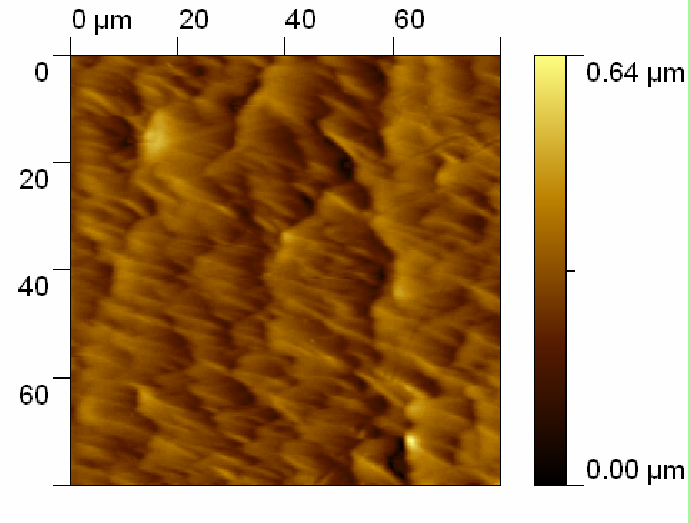
LGNb3 – BCP 100 µm

BCP 100 µm provides the best surface

Surface roughness of SC and LG Nb samples by AFM

measured by X. Singer at DESY



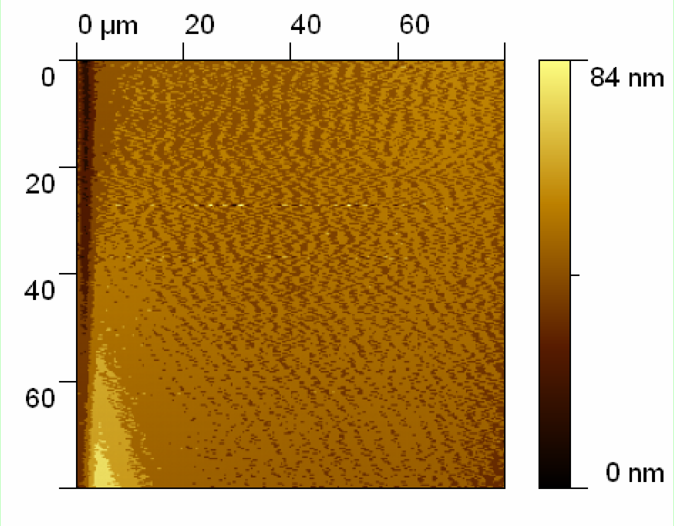


SCNb2, BCP 30 µm

Rms: 17.6 nm

LGNb1, BCP 30 µm

Rms: 62.7 nm



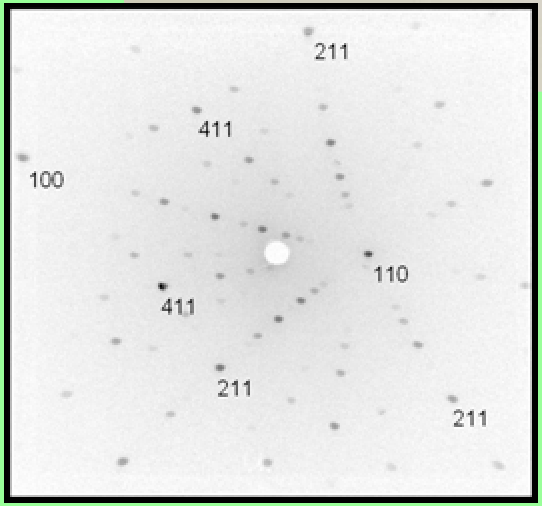
SCNb4, BCP 100 µm

Rms: 7 nm

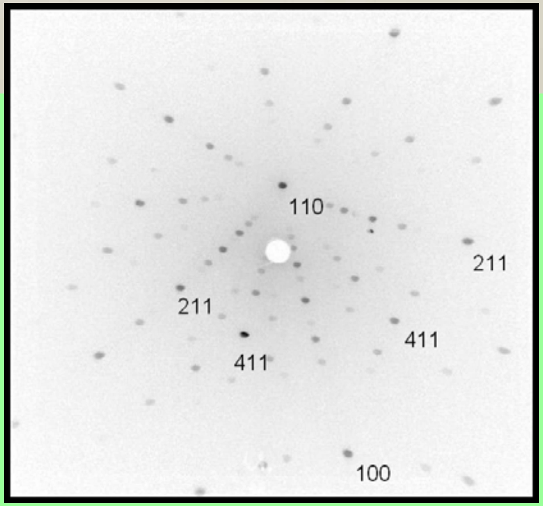
Mirror-like surfaces

Crystal orientation of SC and LG Nb samples by XRD

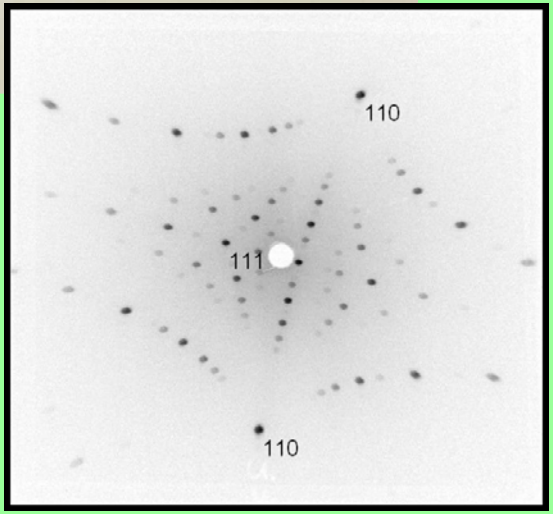
measured by X. Singer at DESY



(110), $\alpha = 15^o$, $\beta = 0^o$



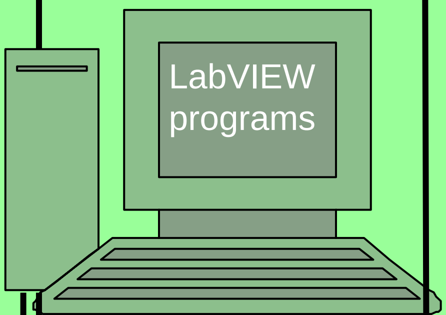
(110), $\alpha = 2^o$, $\beta = 14^o$



(111), $\alpha = 13^o$, $\beta = 4^o$

Field emission scanning microscope (FESM)

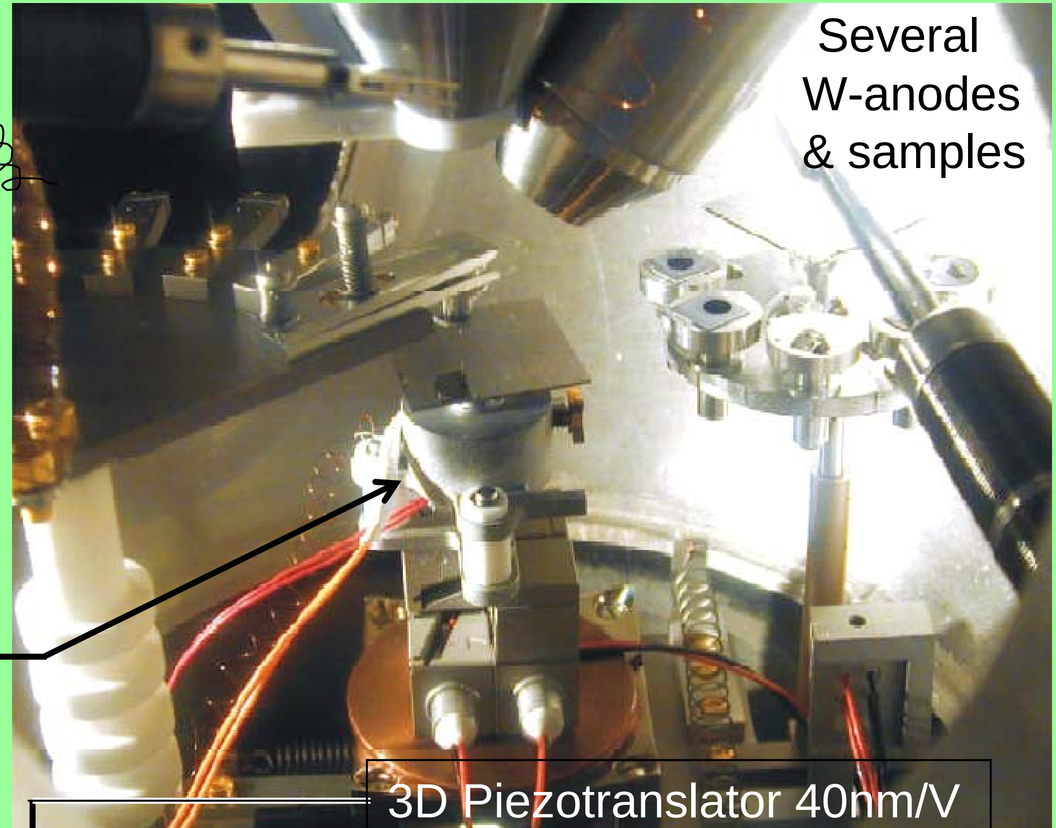
FUG power supply
5 kV, 50mA
PID voltage regulation



Picoamperemeter
Keithley 6485

Motion controller
Newport MM4006

Piezo motion controller
PI- 920126



3D Piezotranslator 40nm/V
XYZ-motors (100nm step)

UHV system typically at $2 \cdot 10^{-7}$ Pa

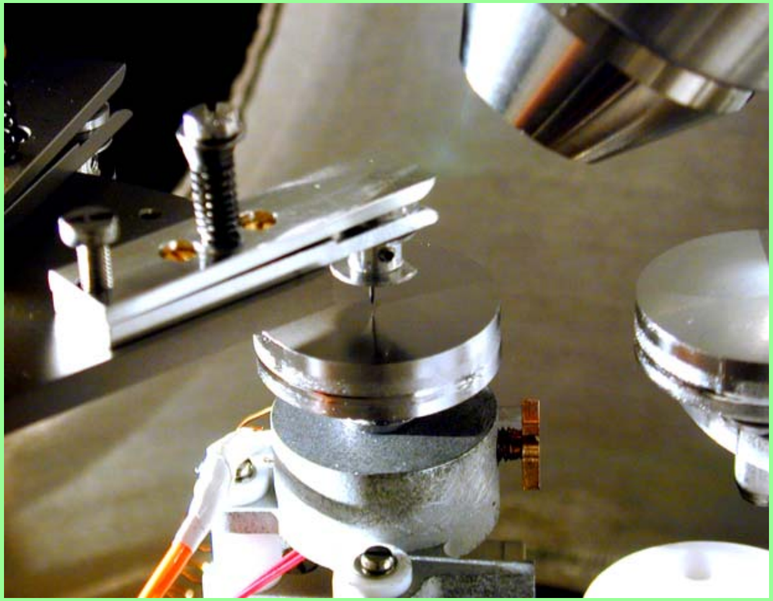
LabVIEW automated scans of U(x,y) for 2 nA

Scanning speed: (100×100) pixels in 1 hr

I/V curves and localization of stable emitters

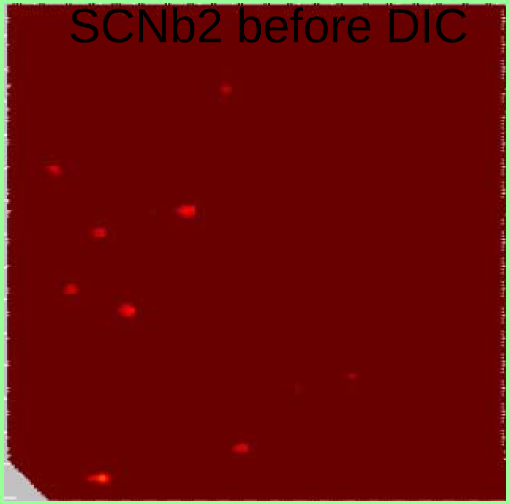
FE suppression of SC and LG Nb samples by DIC

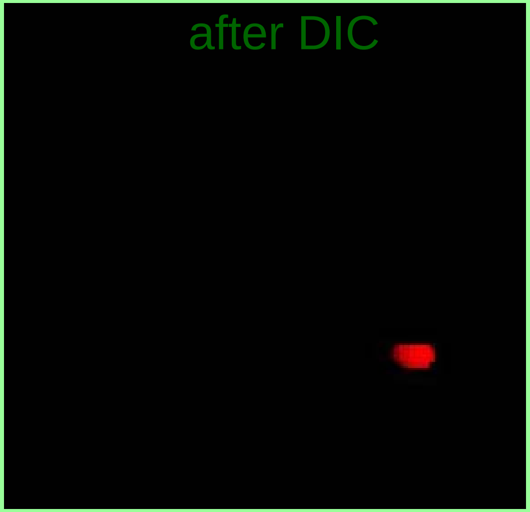
A. Dangwal et al., J. Appl. Phys. 102, 044903 (2007)



Mirrorlike SCNb sample of Ø 28 mm under W tip anode, 1 µm apex radius

PID-regulated voltage maps U(x,y) for 2 nA scan area = 5×5 mm², flat W anode $Ø_a$= 100 µm U_{max} = 5000 V, electrode spacing Δz = 25/20



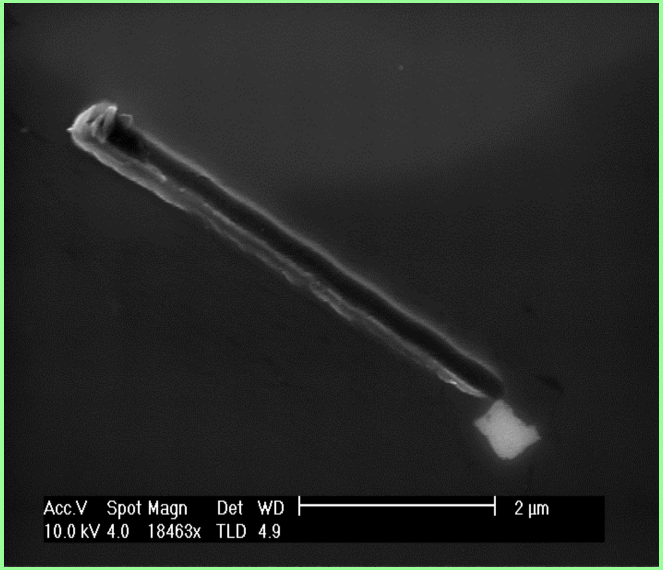


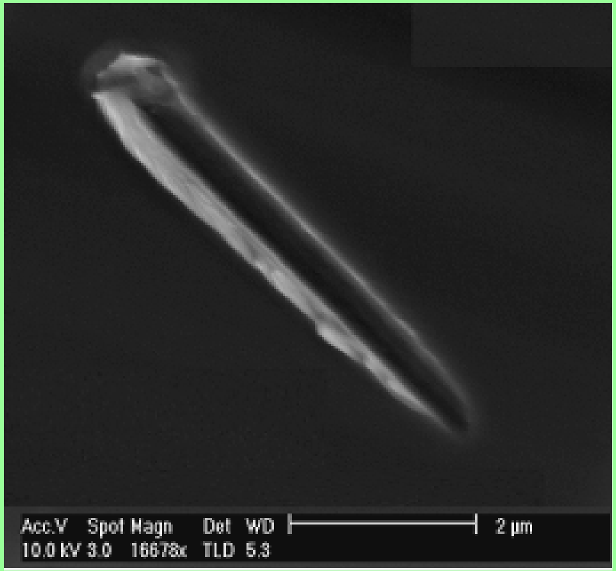
	before DIC	after DIC
SCNb2	no FE @ 120 MV/m	no FE @ 150 MV/m
	9 emit. @ 200 MV/m	1 emit. @250 MV/m
Samples LGNb1, LGNb2, SCNb1 yielded	0, 2, 0 @ 120 MV/m	no FE @ 150 MV/m
	10,12, 5 @ 200MV/m	2, 0 @ 250MV/m

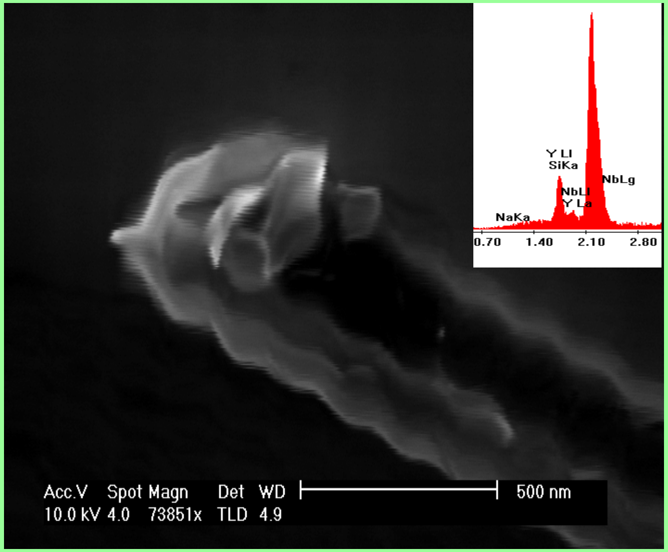
DIC statistically suppresses FE on all type of samples (Cu, Nb)

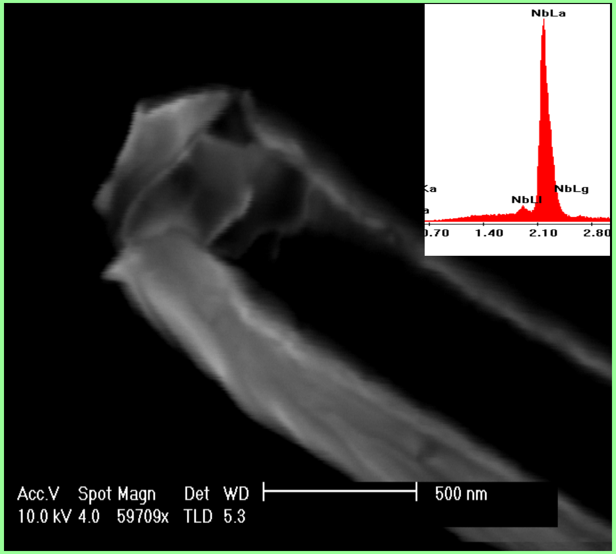
Effect of DIC on scratch-like emitter with small particulate

A. Dangwal et al.
J. Appl. Phys. 102, 044903 (2007)









Removal of 400 nm particulate and

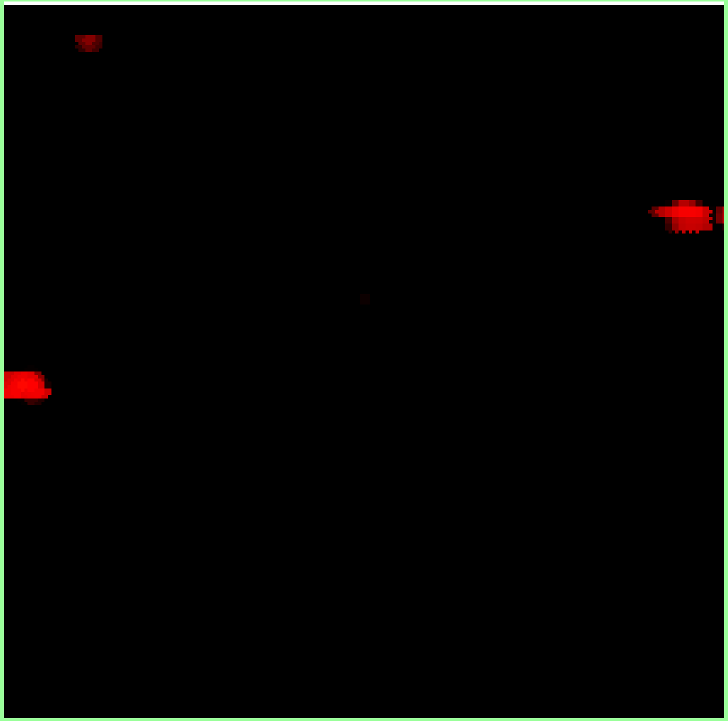
edge smoothing of scratch head on SCNb2 by DIC

E-maps for SCNb1 (BCP30HPR) and SCNb7 (BCP100HPR)

PID-regulated voltage maps U(x,y) for 2 nA
flat W-anode $Ø_a$ = 100 µm
electrode spacing Δz = 25 µm

scanned area = 5×5 mm^2
anode voltage U = 5000 V
Δz = 20 µm

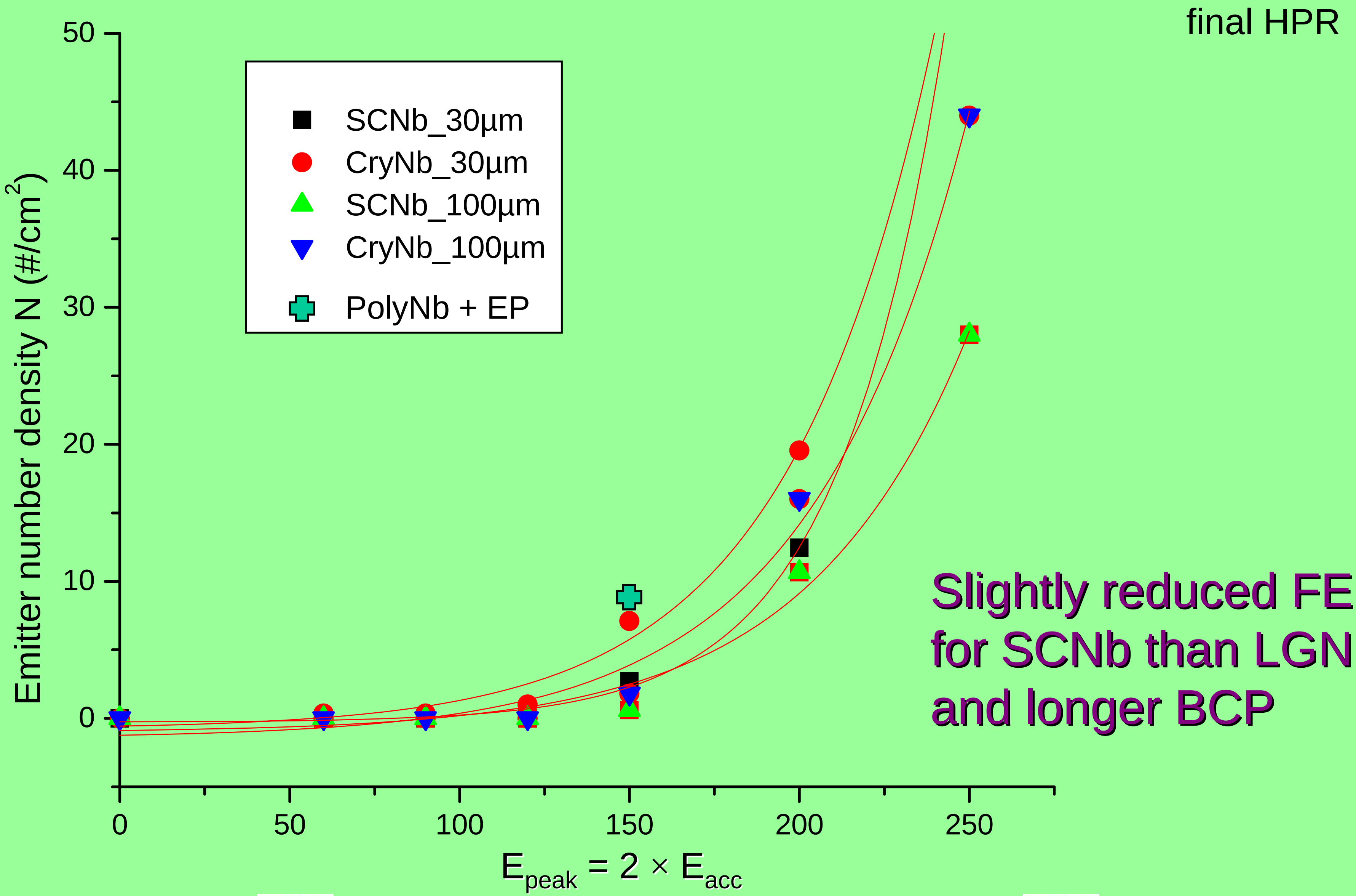
no emission @ 120MV/m
5 emitters @ 200MV/m



no emission @ 150MV/m
3 emitters @ 250MV/m

SCNb + BCP100HPR yields less FE than PolyNb + EP100HPR

Emitter statistics for SCNb and LGNb after BCP 30/100 µm



Slightly reduced FE for SCNb than LGNb and longer BCP

Local I-V curves and identification of emitters on SCNb

$$\ln\left(I(E)/E^{2}\right) = \ln\frac{S\cdot A\cdot\beta^{2}}{\Phi} - \frac{B\cdot\Phi^{3/2}}{\beta}\frac{1}{E}$$

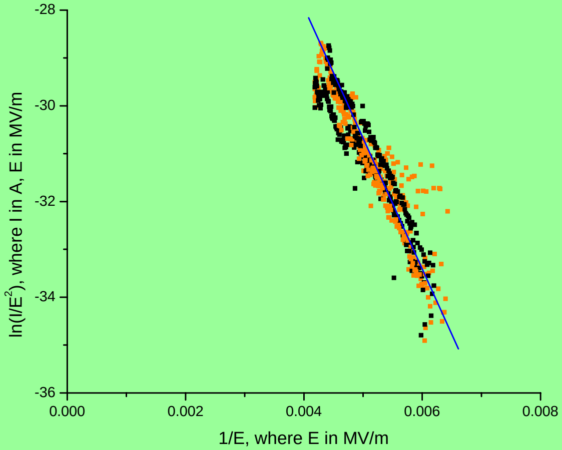
SCNb7

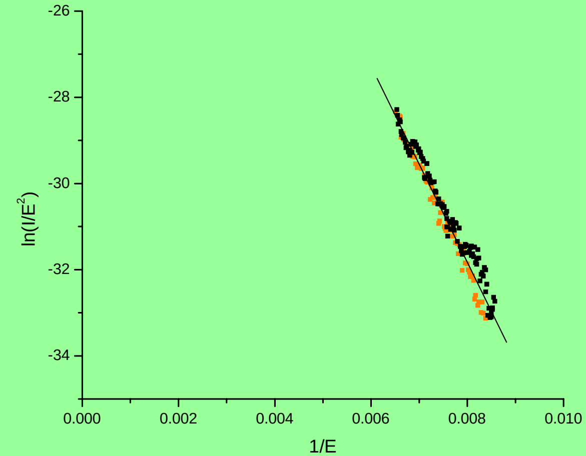
FN-plot with instable FE

E_{on}(2 nA) = 205 MV/m

β = 26

$S=6\cdot10^{-6}$ µm²





SCNb4

FN-plot with stable emit.

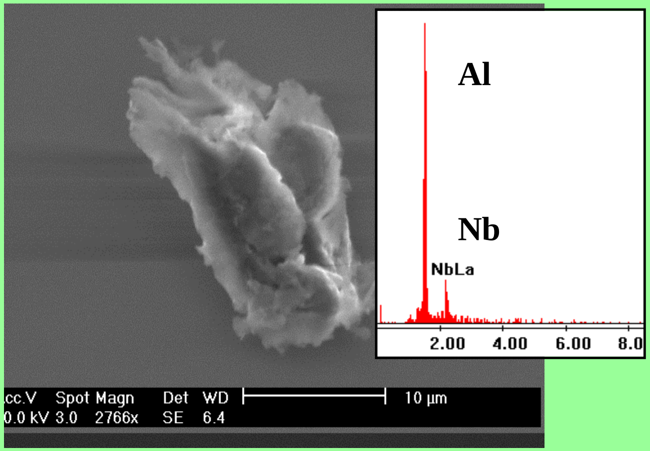
E_{on}(2 nA) = 153 MV/m

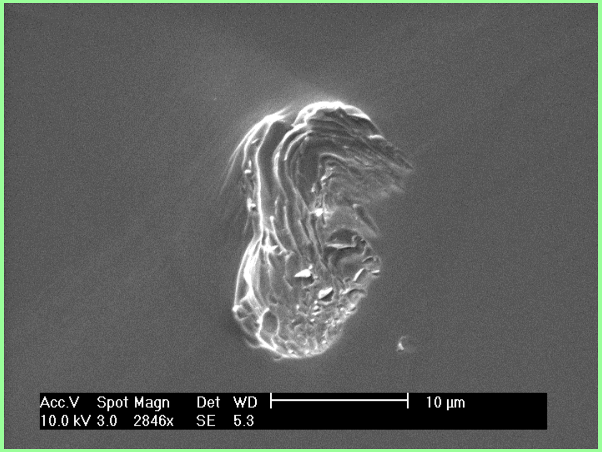
β = 28

$S=2\cdot10^{-4}$ µm²

SEM / EDX reveals Al particulate

mean size ~ 14 µm



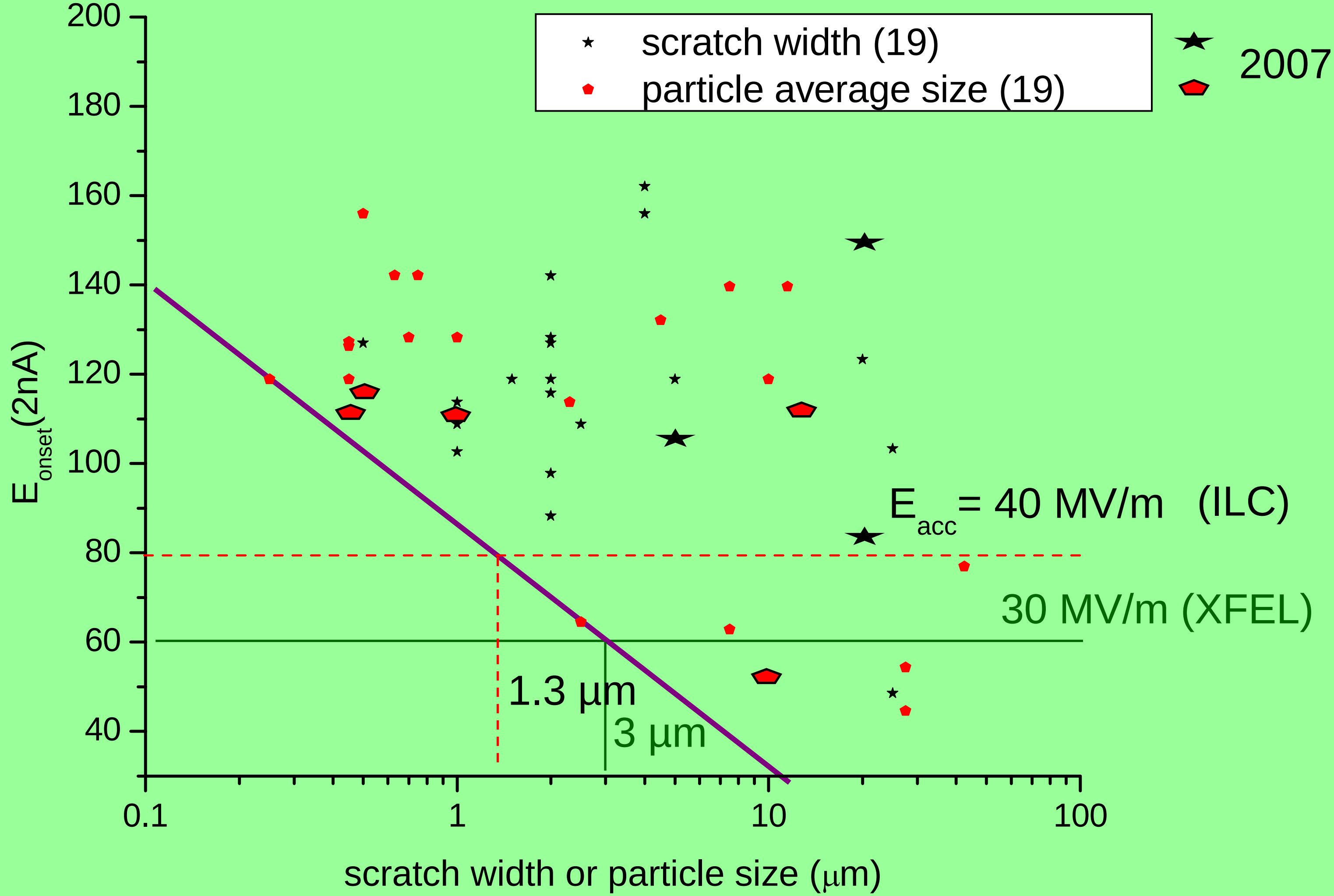


SEM / EDX reveals Nb surface def.

mean size ~ 12 µm

Correlation between FE onset field and defect size ?

based on FE measurements and SEM analysis of 38 field emitters



Evidence for correlation ⇒ fast FE quality control by defect size

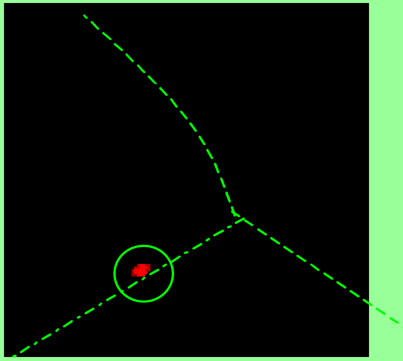
In-situ bakeout at 150 ºC effects on LGNb3 and SCNb4

PID-regulated U(x,y) for 2 nA   scanned area = 5×5 mm^2

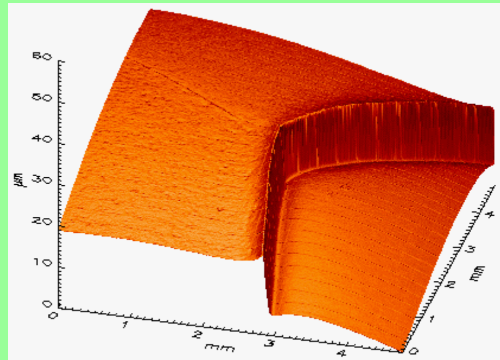
flat W-anode $Ø_a$ = 100 µm, U_{max} = 5000 V, Δz = 25, 20, 16.6 µm

LGNb3

before baking

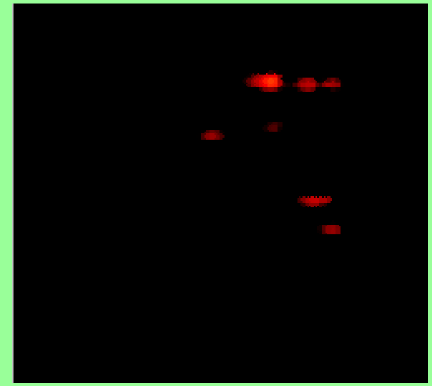


250 MV/m



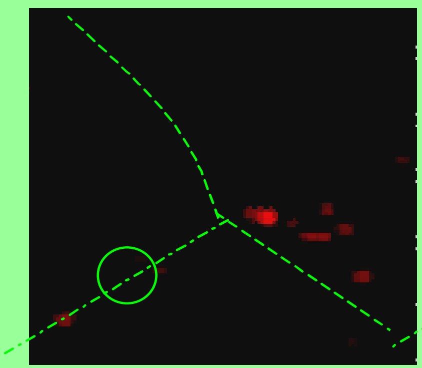
SCNb4

before baking

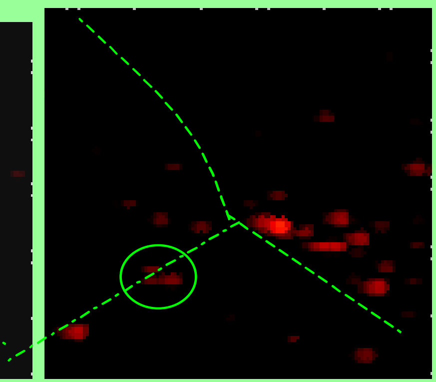


250 MV/m

after 14 h baking at 150 ºC



250 MV/m



300 MV/m

after 8 h baking at 150ºC

250 MV/m

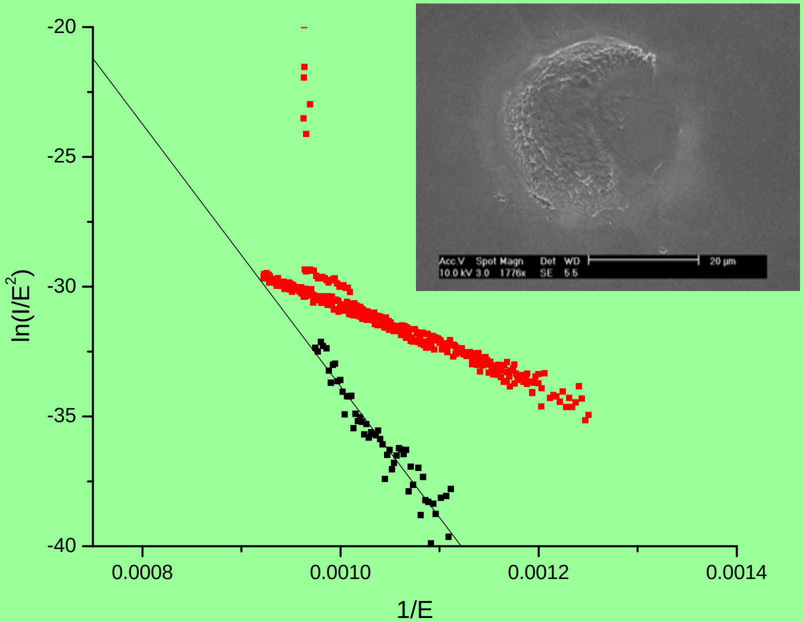
After Baking more emitters appear for LG but not for SC at E > 250MV/m

⇒ **first evidence for impurity segregation to grain boundaries**

Intrinsic FE of SCNb in defect-free sample areas

measured with W-tip anodes of $Ø_a$ = 5-10 µm at U = 5000 V and Δz > 1 µm

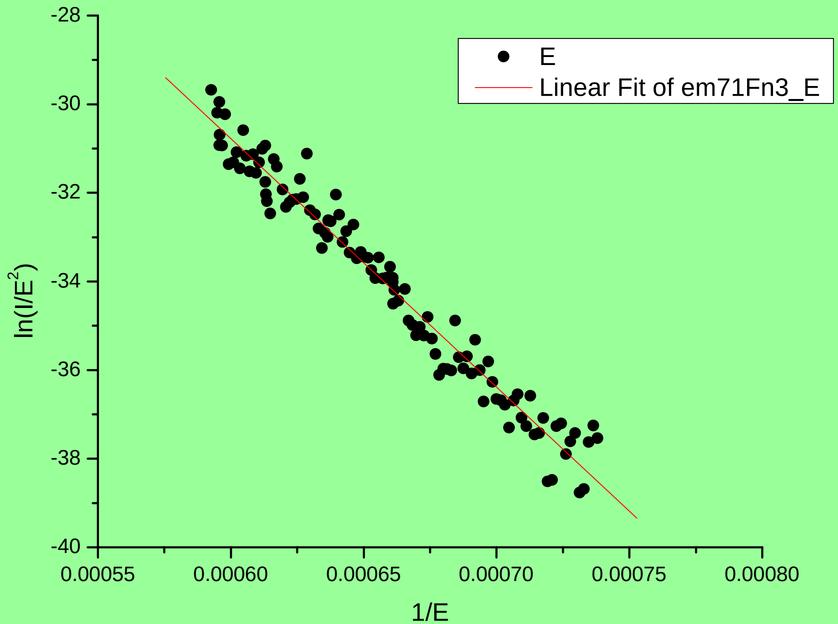
SCNb4, (111) orientation



Initially intrinsic field emission of Nb with slope β = 1 ⇒ Φ = 3.8 eV

creation of an emitter at ~ 1000 MV/m by a microdischarge ⇒ crater in Nb

SCNb7, (100) orientation



Intrinsic field emission of Nb
slope β = 1 ⇒ Φ = 4 eV

⇒ SCNb samples reveal anisotropy of work function Φ

Conclusions and outlook for FP7

- DIC effectively removes particulates and weakens protrusions
  ⇒ **in situ repair cleaning of FE cavities in module !** (JAP102, 2007)

- Large/single crystal Nb samples show after BCP30/100-HPR better FE results than EP-HPR samples of various kinds
  ⇒ **reliable alternative for SRF cavities with less FE !** (SRF 2007)

- Evidence for a correlation between onset field and emitter size
  ⇒ **fast FE quality control on samples for XFEL !** (SRF 2007) + FP7

- Evidence for impurity segregation to grain boundaries in LGNb after bakeout at 150ºC ⇒ **reduced FE in SCNb !** (SRF 2007) + FP7

- Intrinsic FE on SCNb with $\beta = 1$ and $\Phi = 4$ eV partially obtained
  ⇒ **surface roughness enhances FE of particulates !** (SRF 2007)

PhD thesis of A.Dangwal will be presumably available in November 2007

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