Advances in Large Grain/Single Crystal SC Resonators at DESY

Presented by W.Singer

Participants

X.Singer, H.Wen, A.Ermakov (DESY, MPL)
D. Proch, A.Brinkmann, J.Iversen, G.Kreps, D.Reschke (DESY, MHF-SL)
A.Matheisen, A.Schmidt (DESY, MKS3)
M.Spiwek (DESY HASYLAB)
P.Kneisel (JLab)
K.Kowalski, A.Bernasik (SSL, Krakow)
A.Dangwal, G.Mueller (UNI Wuppertal)
K.-R. Baldner, J. Van Santen (RWTH Aachen)

H.-G. Brokmeier (TU Clauthal)

Outlook

- LG: Fabrication and some results
- SC: Fabrication and some results
- Material investigation

Large grain/single crystal cavity

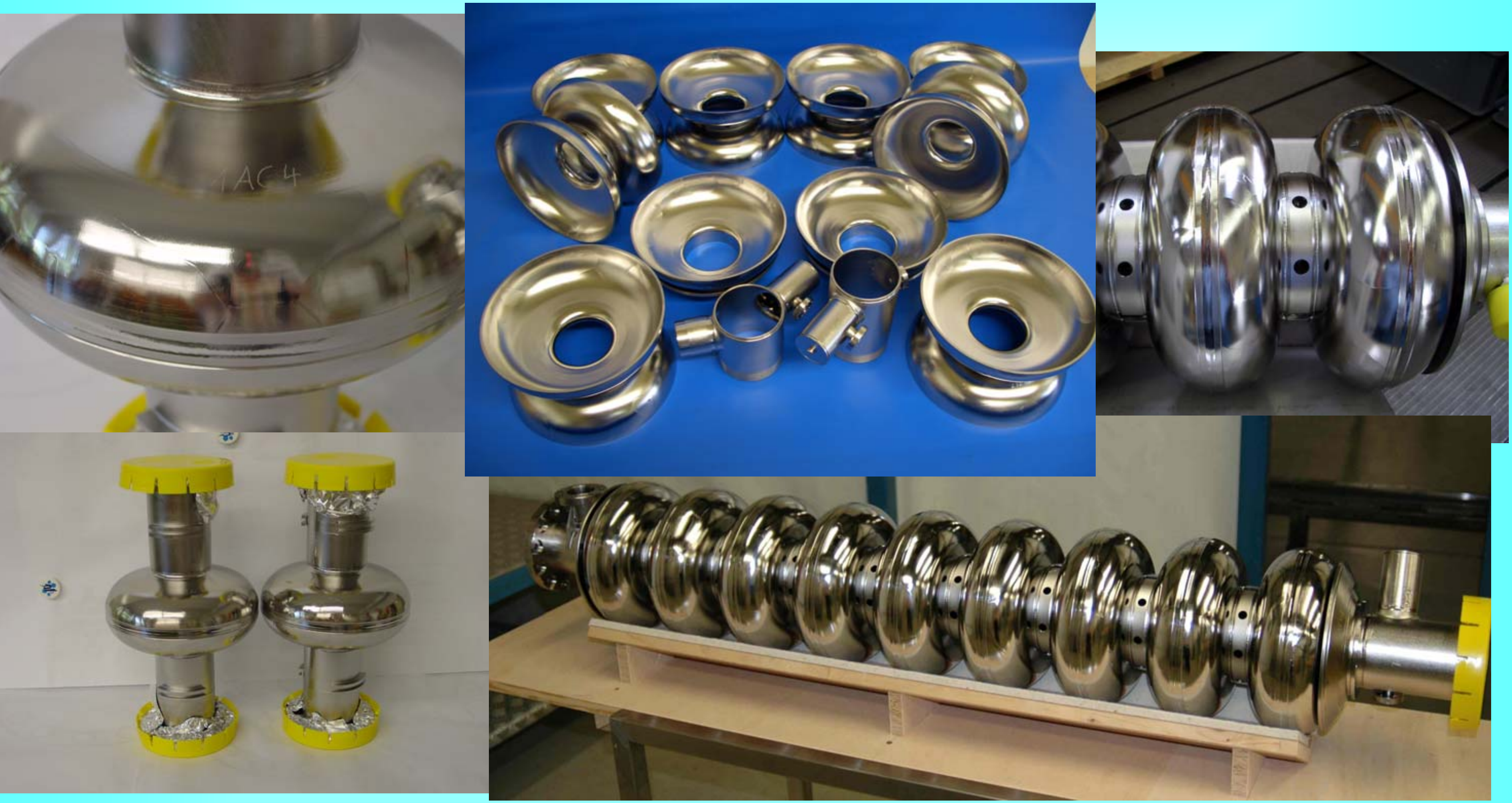
Possible advantages:

- Cost effective
- Higher purity. RRR=600 of ingot is achievable
- No danger that during many steps from ingot to sheet the material will be polluted.
- Simplified quality control (reduced number of measurements: grain size, eddy current scanning etc.)
- Higher thermal conductivity at low temperatures (phonon peak)
- Higher quality factor Q of the cavity is to expect (less RF losses on grain boundaries)
- Possibly simplified cavity treatment (BCP instead EP) could be applied
- Less susceptible to field emission
- Seems that the baking at 120°C works better

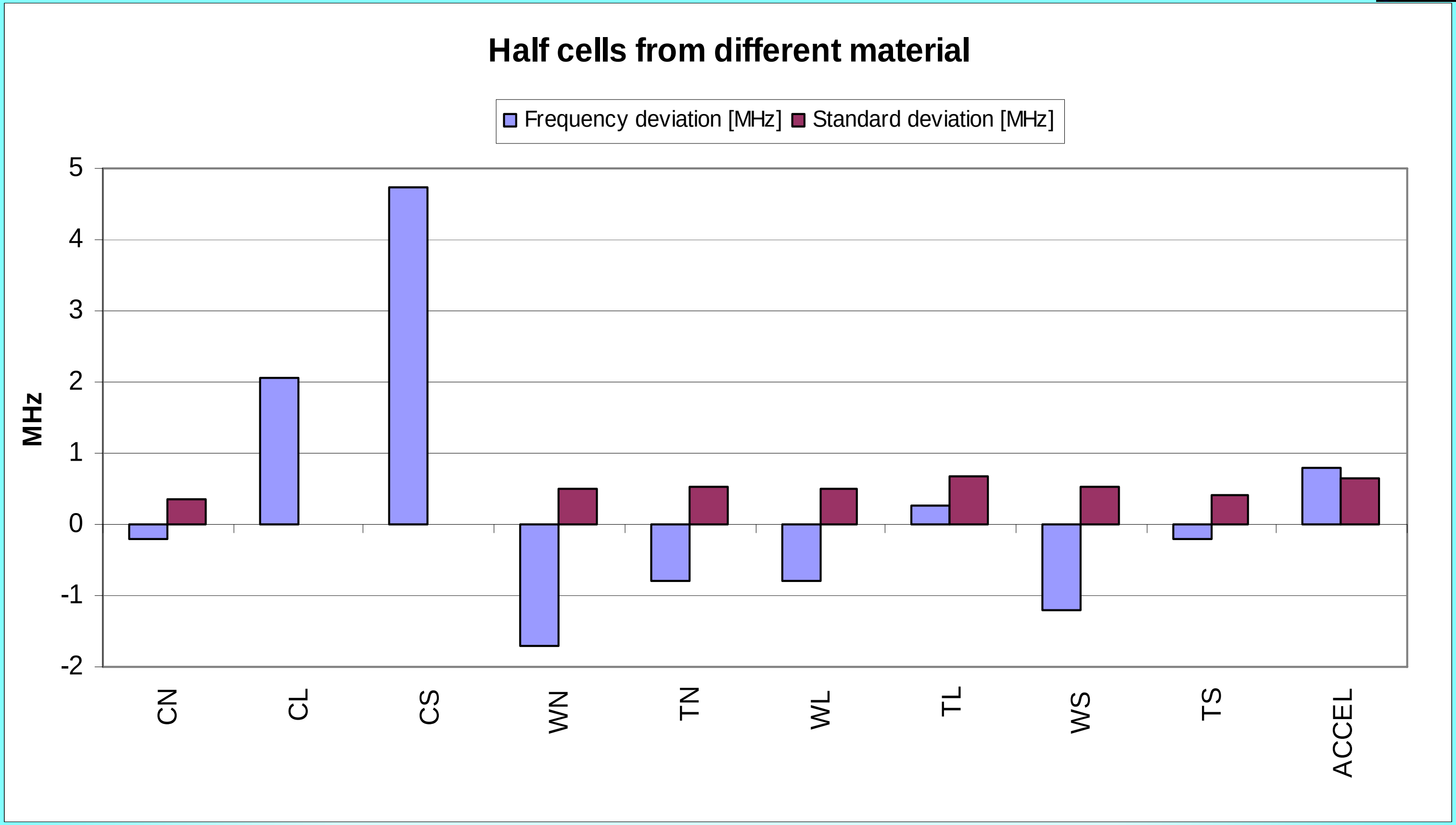
DESY LG/SC R&D program

Material of the company	RRR	No./Type	Fabrication by	Fabrication Procedure	Status, November 2006
		1-cell cavity			
Heraeus/LG	500	1AC3	ACCEL	Deep drawing + EB welding	Tested after EP, tested after BCP
Heraeus/LG	500	1AC4	ACCEL	Deep drawing + EB welding	Tested after EP, tested after BCP
Heraeus/LG	500	1AC5	ACCEL	Spinning + EB welding	Tested after EP and BCP
CBMM/SC	200	1AC6	ACCEL	Spinning + EB welding	Tested after BCP and EP
Heraeus/LG	340	1AC7	ACCEL	Deep drawing + EB welding	Tested after BCP, In EP treatment
Heraeus/SC	300	1AC8	ACCEL	Deep drawing + EB welding	In BCP treatment
Heraeus/LG	300	1DE20	DESY	Deep drawing + EB welding	Produced
Heraeus/LG	300	1DE21	DESY	Deep drawing + EB welding	Produced
Ningxia/LG	400	1DE22	DESY	Deep drawing + EB welding	Produced
CBMM/LG	250	1DE25	DESY	Deep drawing + EB welding	In fabrication
NPC/LG	240	1DE26	DESY	Deep drawing + EB welding	In fabrication
		9- cell cavity			
Heraeus/LG	340	AC114	ACCEL	Deep drawing + EB welding	Tested after BCP
Heraeus/LG	370	AC113	ACCEL	Deep drawing + EB welding	Tested after BCP
Heraeus/LG	500	AC112	ACCEL	Deep drawing + EB welding	Tested after BCP

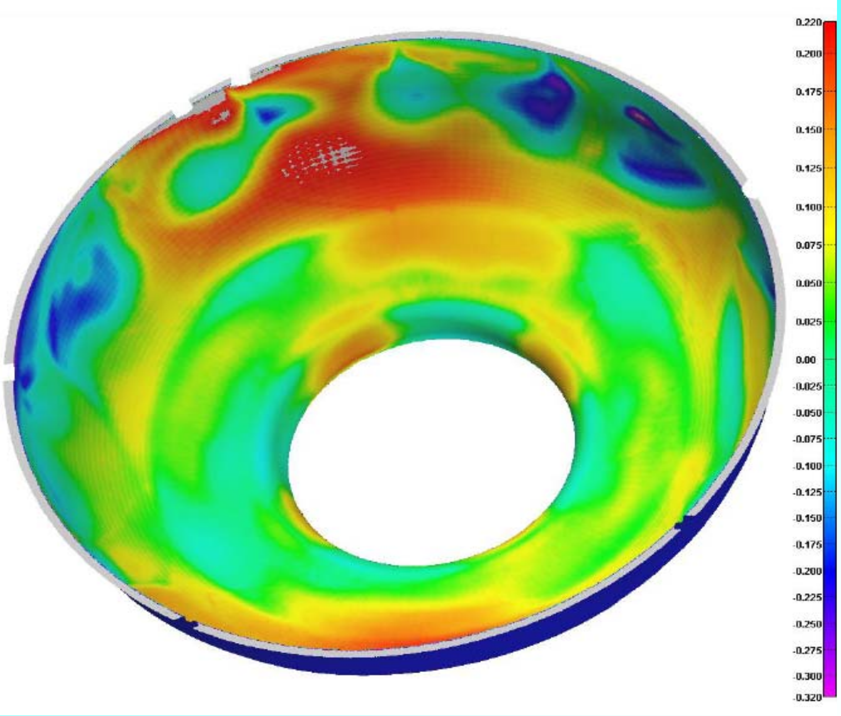
Large Grain: Several 1-cell and three 9-cell cavities fabricated (ACCEL)

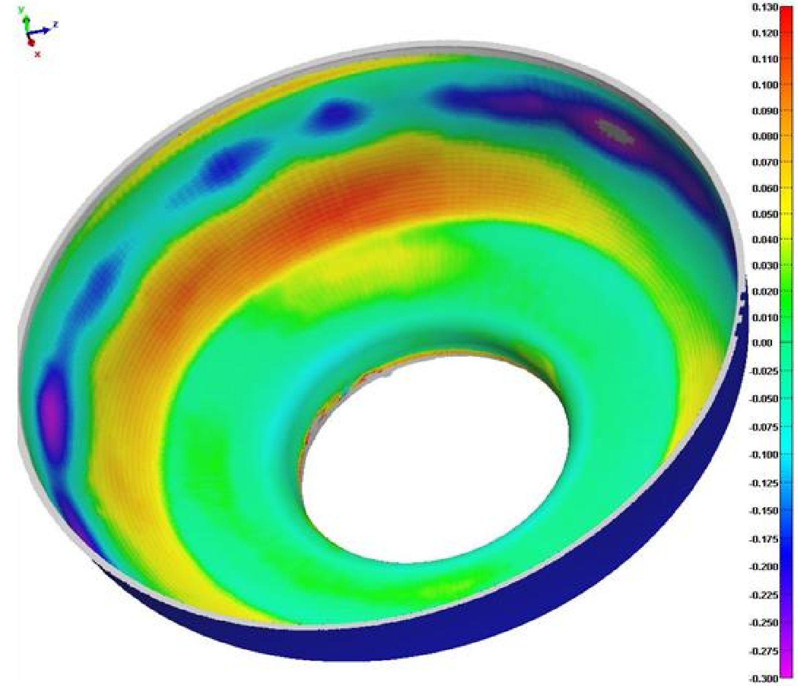


The surface is more shiny after BCP. The steps at grain boundaries are more pronounced as in polycrystalline material.



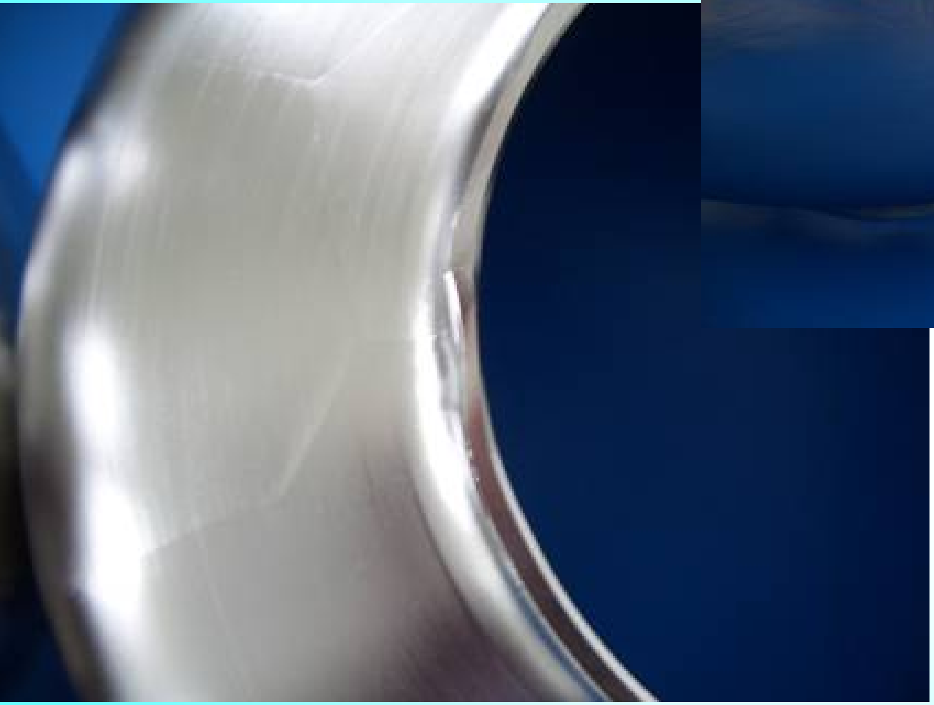
Frequency measurement of 6 end half cells (L and S) and 48 middle half cells (N) for cavities AC112-114. C - large crystal, W - Wah Chang, T - Tokyo Denkai. The shape conformity of half cells from large grain material is lower as of conventional fine grain (could be improved by correction of the tools), the uniformity of the half cells from large grain material is better.





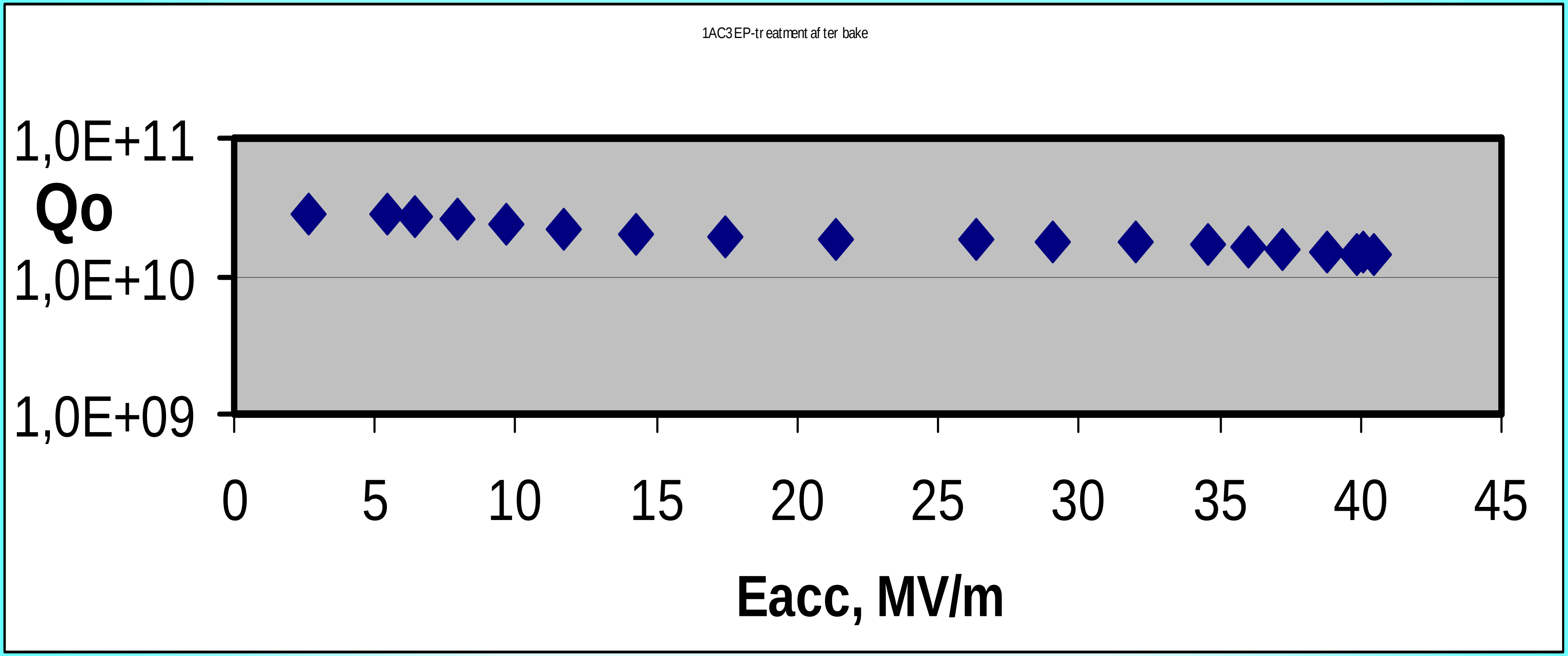
3D Image of the optical measurement of the shape on large grain half cell (left; realized accuracy +0,22 / -0,32 mm) in comparison with a fine grain half cell (right; realized accuracy +0,13 / -0,30 mm). The large grains are fractionally pronounced. The variation of the large grain half cell shape is somewhat larger

Deep drawn half cell of HERAEUS large grain niobium; Large single crystal at centre, no problems on iris area



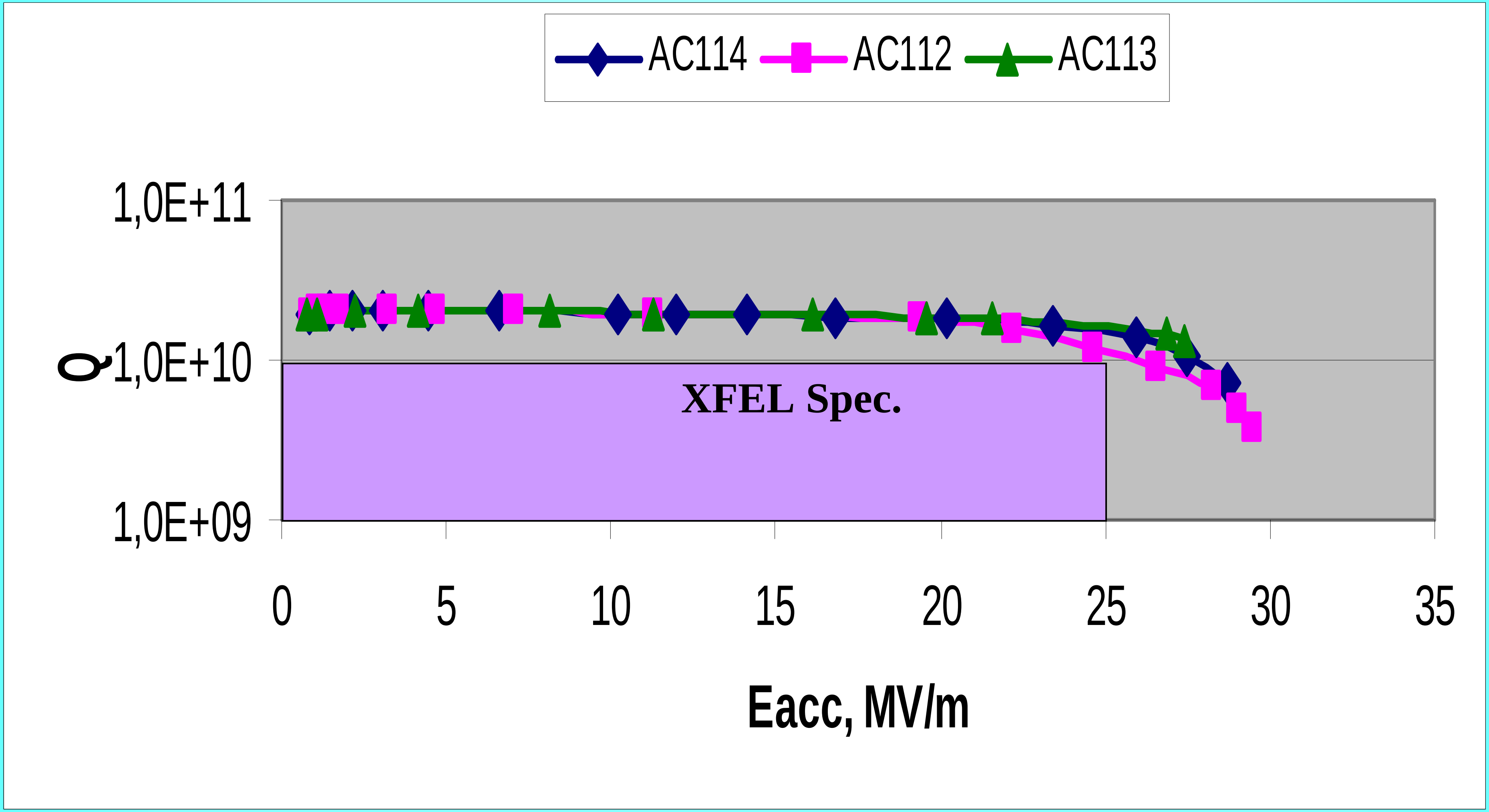
Deep drawn half cells of Ningxia LG Nb;

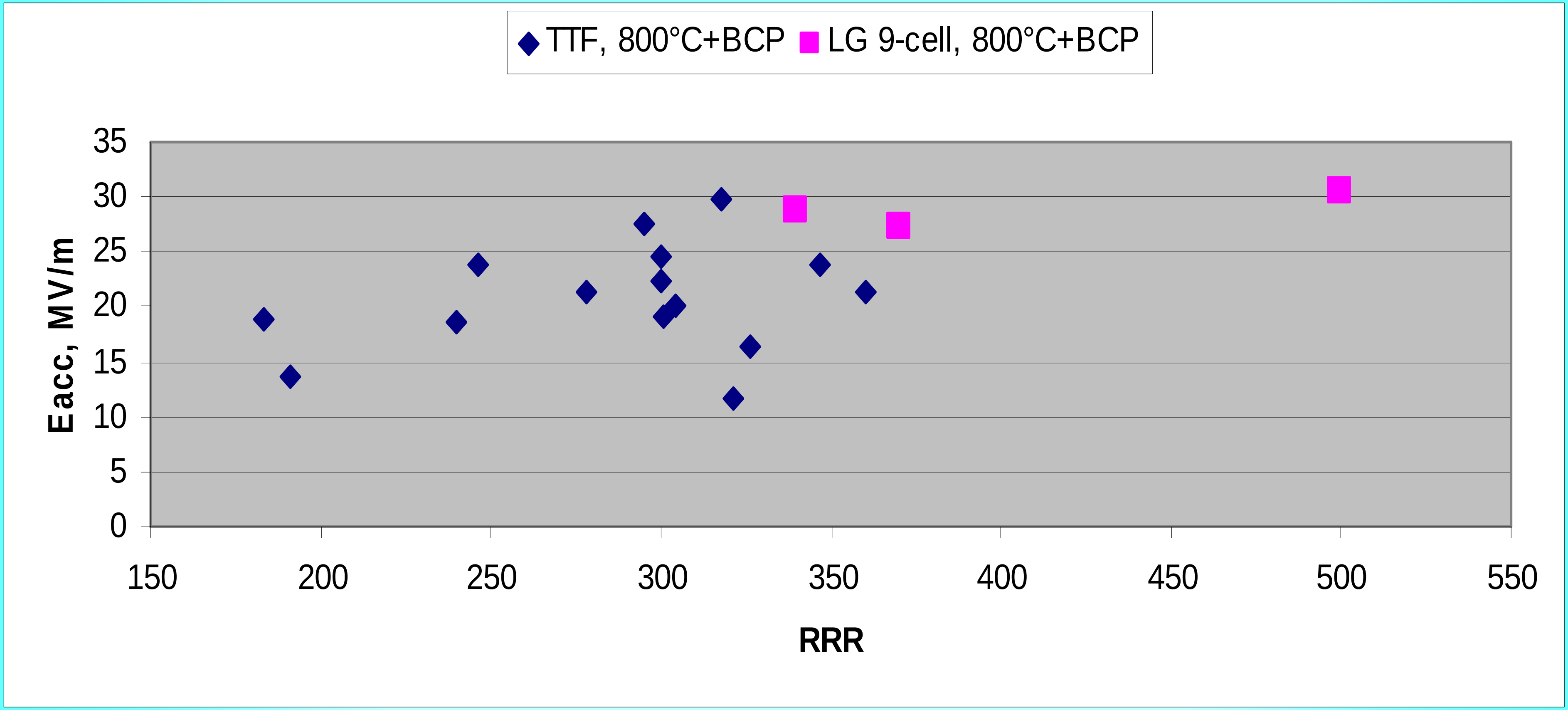
- thinning at grain boundary in iris region
- Strong earing and grain steps at equator region



Q(Eacc) curve of the large grain single cell cavity 1AC3 after EP treatment

First test Q(Eacc) curve of the LG nine cell cavities AC112- AC114 after 800°C+BCP treatment





Comparison of the Eacc performance of large grain (LG) 9-cell cavities with similarly treated TTF cavities

Summary of RF Tests for LG Nb

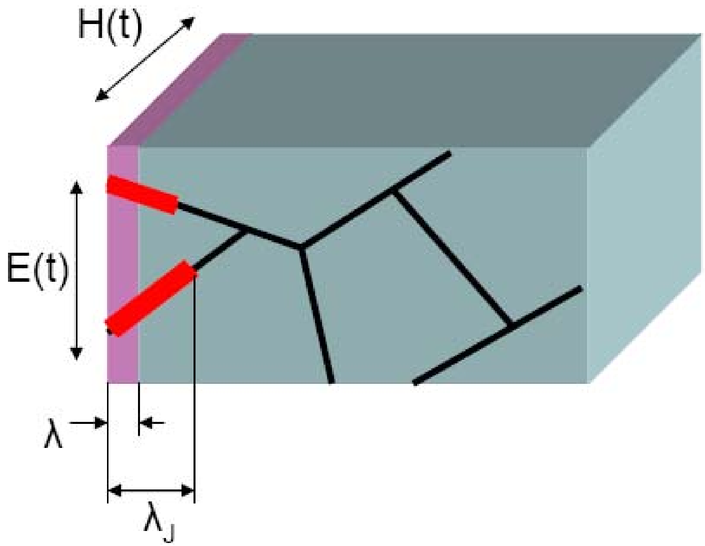
Material of the company	No./Type	Treatment	Eacc, MV/m	Qo at Eacc=23.5	Limitation
Heraeus/large grain	1AC3/single cell	190µm **EP**, 800°C 2h, 120°C 48h, HPR	41.2	3.2E+10	Quench at equator
Heraeus/large grain	1AC4/single cell	190µm **EP**, 800°C 2h, 128°C 48h, HPR	38.5	2.3E+10	Quench at equator
Heraeus/large grain (spinning)	1AC5/single cell	275 µm **EP**+**BCP**, 800°C 2h, 135°C 48h, HPR	29.7	2.0E+10	Quench, not equator
Heraeus/large grain	1AC7/single cell	220µm **BCP**, 800°C 2h, 120°C 48h, HPR	25.3	3.0E+10	Quench (no TM)
Heraeus/large grain	AC112/nine cell	200 µm **BCP**, 800°C, HPR	30,5	2.0E+10	Field Emission FE
Heraeus/large grain	AC113/nine cell	160µm **BCP**, 800°C, HPR	27,4	2.0E+10	Quench at equator
Heraeus/large grain	AC114/nine cell	120µm **BCP**, 800°C, HPR	28.7	2.1E+10	Quench probably FE induced

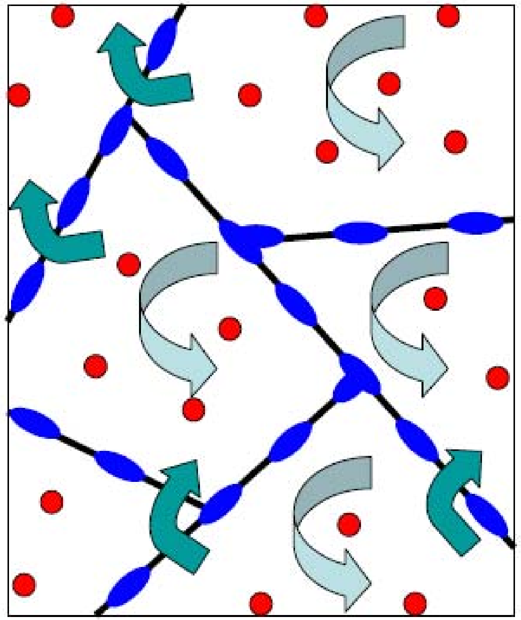
Grain boundaries GBs contribute to reduction of the cavity performance

- responsible for magnetic field enhancement (steps on GBs after BCP)
- make easier the penetration of external magnetic field (GBs are planar weak links with reduced critical current density)
- additional RF resistance due to vortices penetrating along the grain boundary (reduce the quality factor Qo)
- make easier the hydrogen absorption and diffusion
- gathered impurities (reduced RRR)
- reduce the thermal conductivity at low temperatures (reduced phonon contribution)
- possibly make worse the baking (oxides and impurities in grain boundaries)
- possibly make worse high pressure water rinsing (enhance the surface roughness)

Fine grain Nb sheet corresponds to length ~ 3000 m, LG Niobium corresponds to length ~ 3 m (B. Spaniol, Linac2006)

Effect of grain boundaries





- GBs are planar weak links with excess resistance R_b and reduced critical current density J_b

$$\lambda_J = (\lambda\xi)^{1/2}\sqrt{\frac{J_d}{J_b}} >> \lambda$$

- RF field leaks in through the GB network
- GB vortices are different from intragrain ones

$$H_p = \frac{2H_c}{\pi}\sqrt{\frac{2\xi J_d}{\lambda J_b}} << H_c$$

For $J_d \sim 3$ MA/mm² and $J_b \sim 10^{-2}$ MA/mm², $\lambda_J \sim 17\lambda$, and $H_p \sim 0.16H_c$

A.Gurevich, Pushing the Limits of RF Superconductivity, ANL, 22-24 September, 2004

Dream:

Single Crystal

P.Kneisel, JLab

HG Cavity Shape:2.3 GHz

E_{peak}/E_{acc} = 1.674

H_{peak}/E_{acc} = 4.286 mT/MV/m

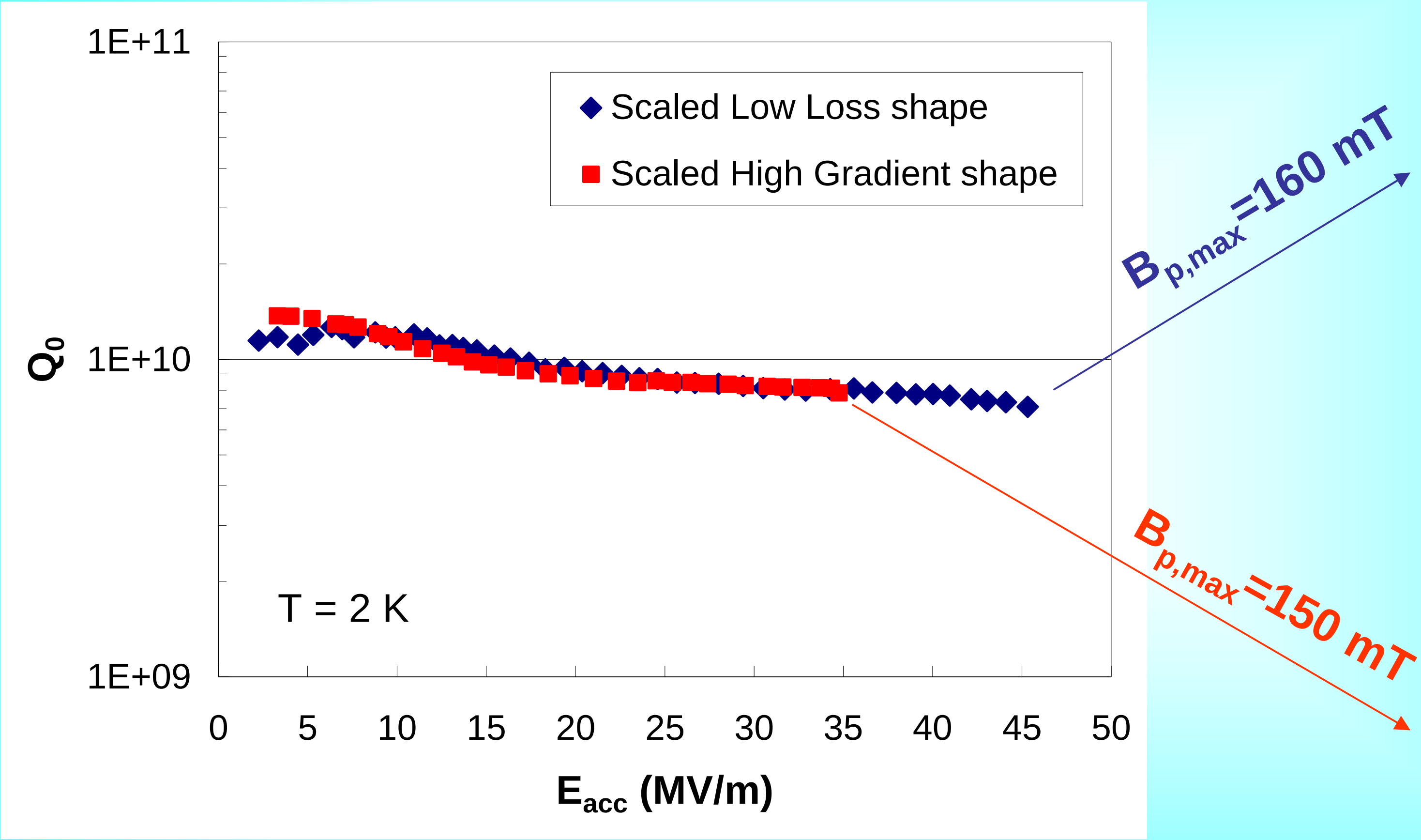
ILC LL cavity Shape:2.3 GHz

E_{peak}/E_{acc} = 2.072

H_{peak}/E_{acc} = 3.56 mT/MV/m

Single-crystal cavities

2.3 GHz single-cells, treated by BCP



P. Kneisel et al., Proc. of PAC'05, Knoxville, TN, 2005, p. 399

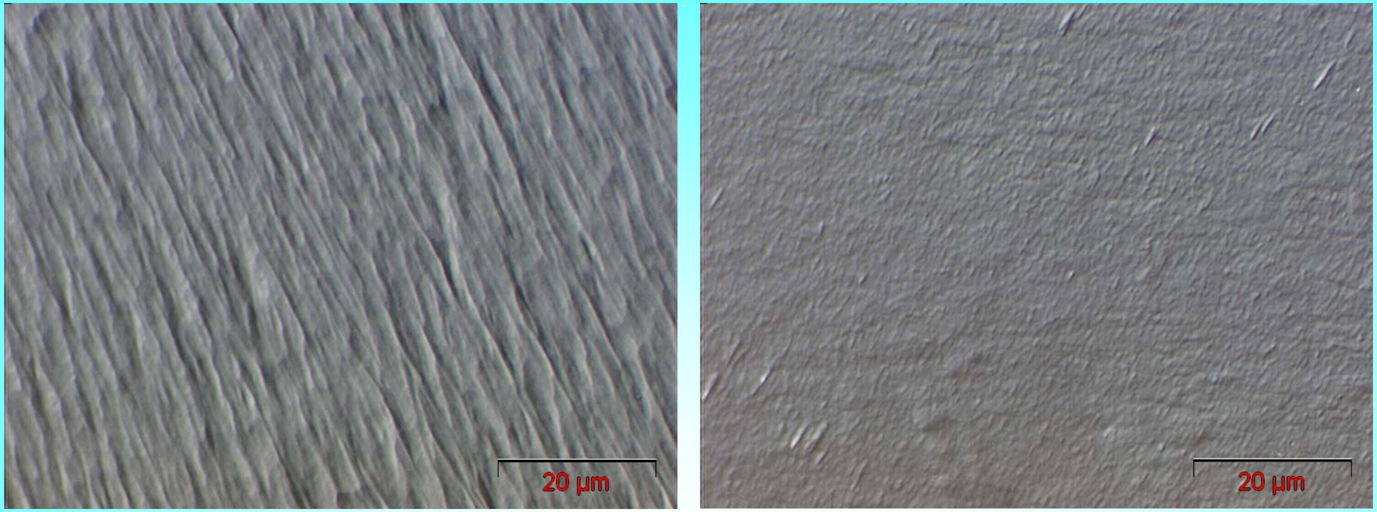
Is it possible produce single crystal cavities of dimensions required for ILC?

Fabrication of TESLA shape single crystal single cell cavities proposed.

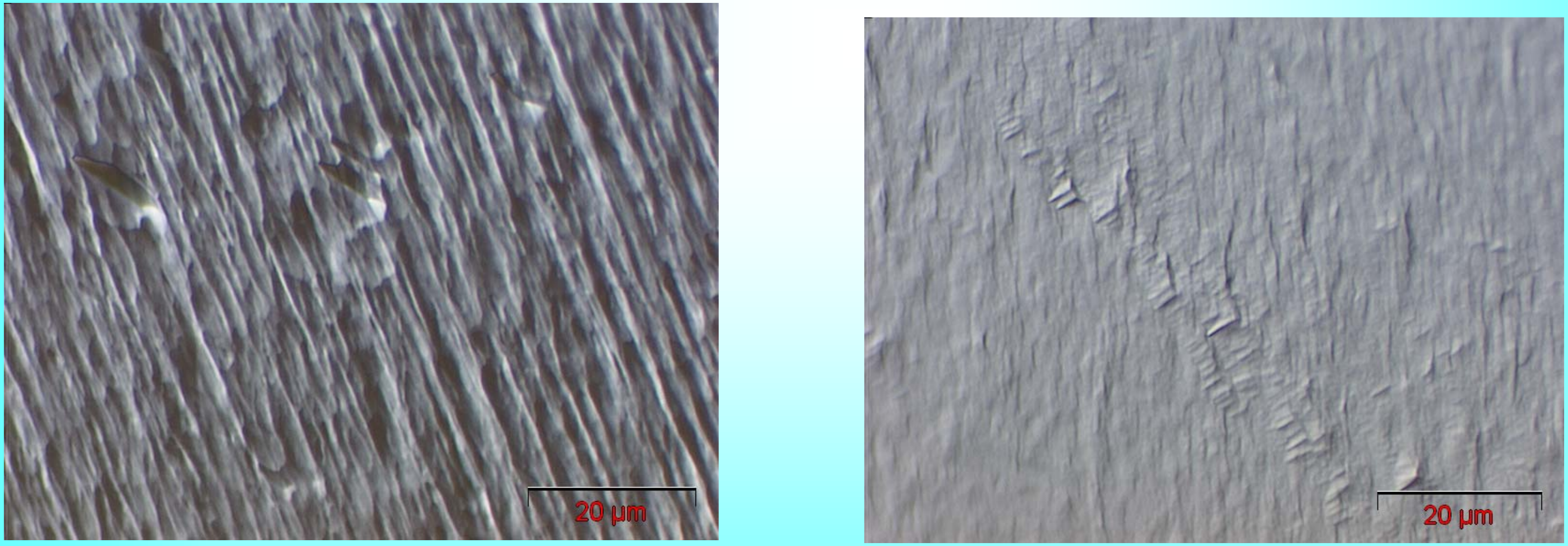
Following aspects have been investigated and taken into consideration during cavity fabrication

- Definite enlargement of the discs diameter is possible without destroying the single crystal structure in an existing state.
- Appropriate heat treatment will not destroy the deformed single crystal
- The single crystals keep the crystallographic structure and the orientations after deep drawing and annealing at 800°C
- Two single crystals will grow together by EB welding, if the crystal orientations is taken into account.

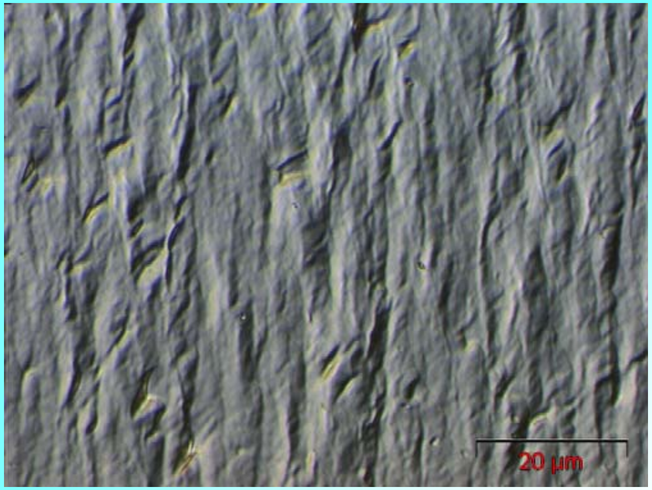
What deformation degree can withstand the SC?

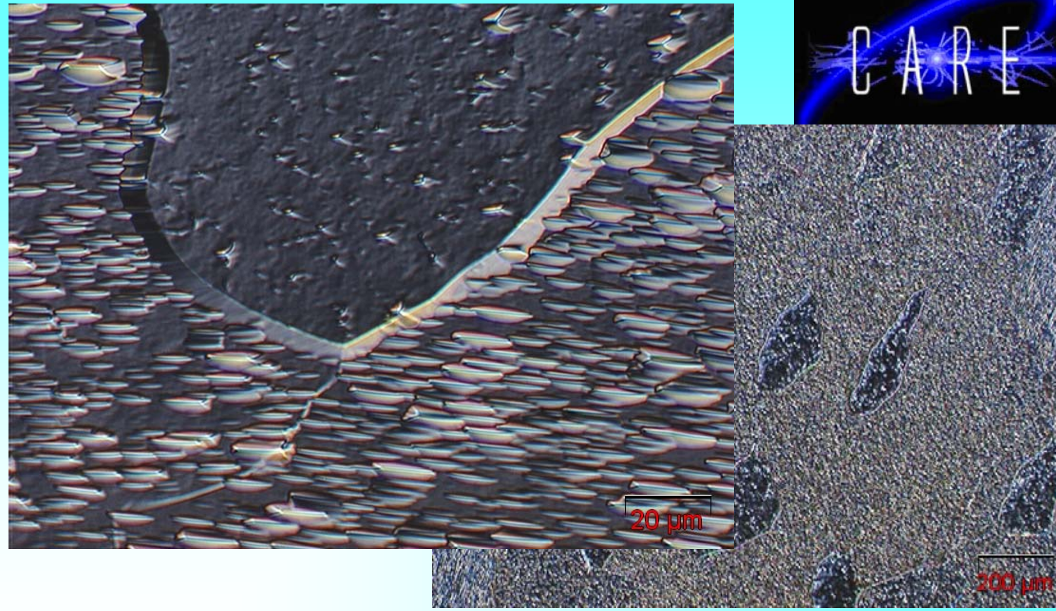


Nb single crystal after deformation degree of 60% (left) and annealing (right)

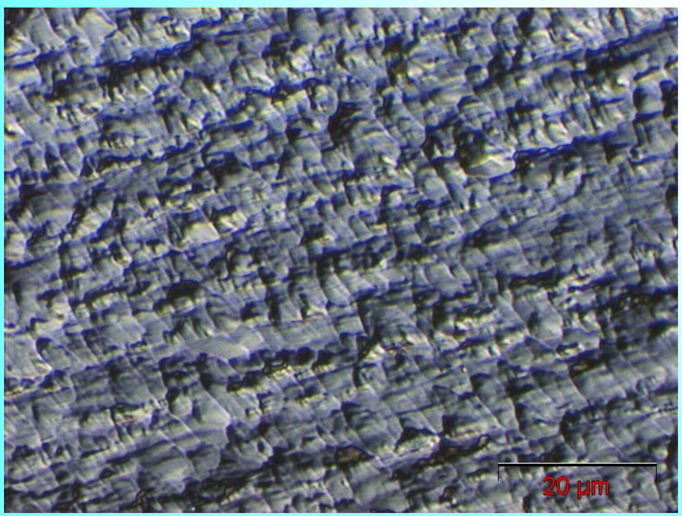


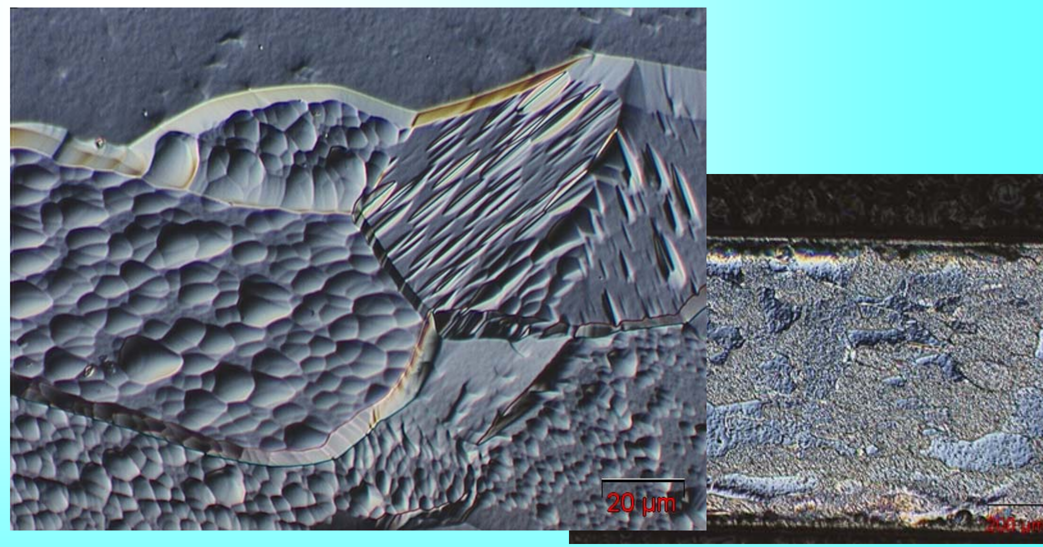
Nb single crystal after deformation degree of 70% (left) and annealing (right)



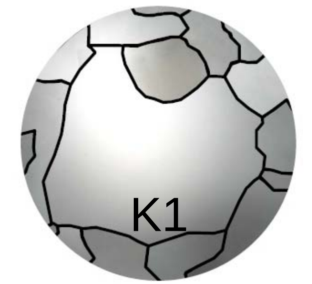


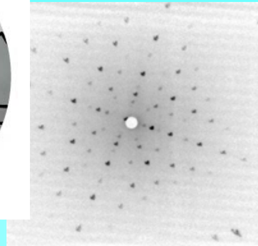
Nb single crystal after deformation degree of 80% (left) and additional annealing (right)





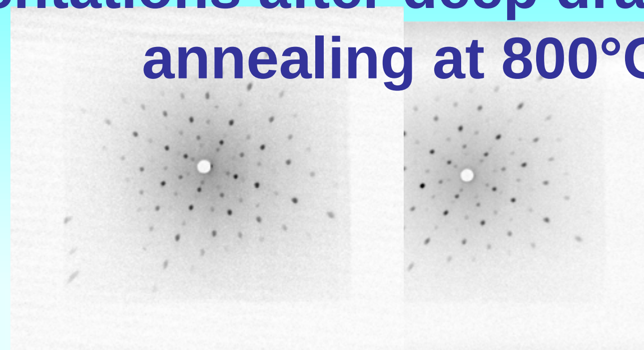
Nb single crystal after deformation degree of 90% (left) and annealing (right)



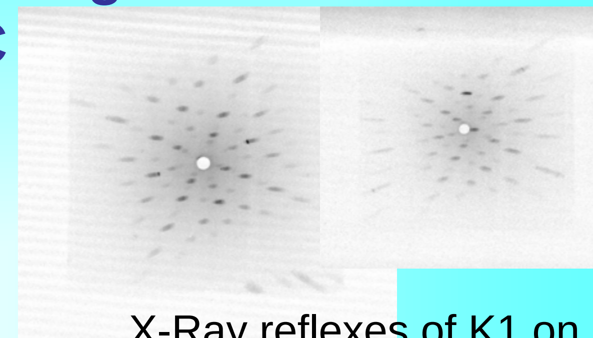


Single crystals keep the crystallographic structure and the orientations after deep drawing and annealing at 800°C

X-Ray reflexes of the central crystal K1 in the flat disc. Orientation (100)



X-Ray reflexes of K1 on position 1 before (above) and after annealing at 800°C, 2hs

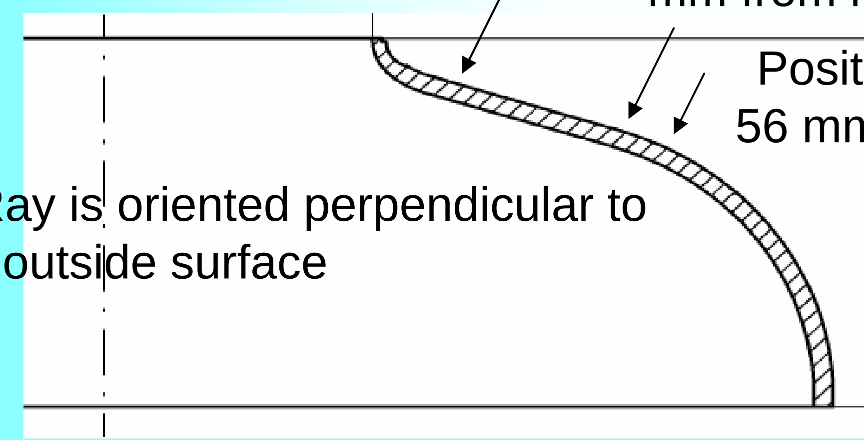


X-Ray reflexes of K1 on position 2 before (above) and after annealing at 800°C, 2hs

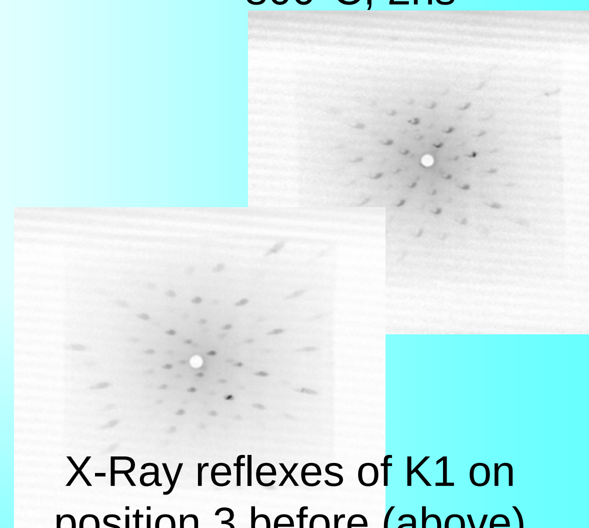
Position 1 ca. 20 mm from iris

Position 2 ca. 50 mm from iris

Position 3 ca. 56 mm from iris



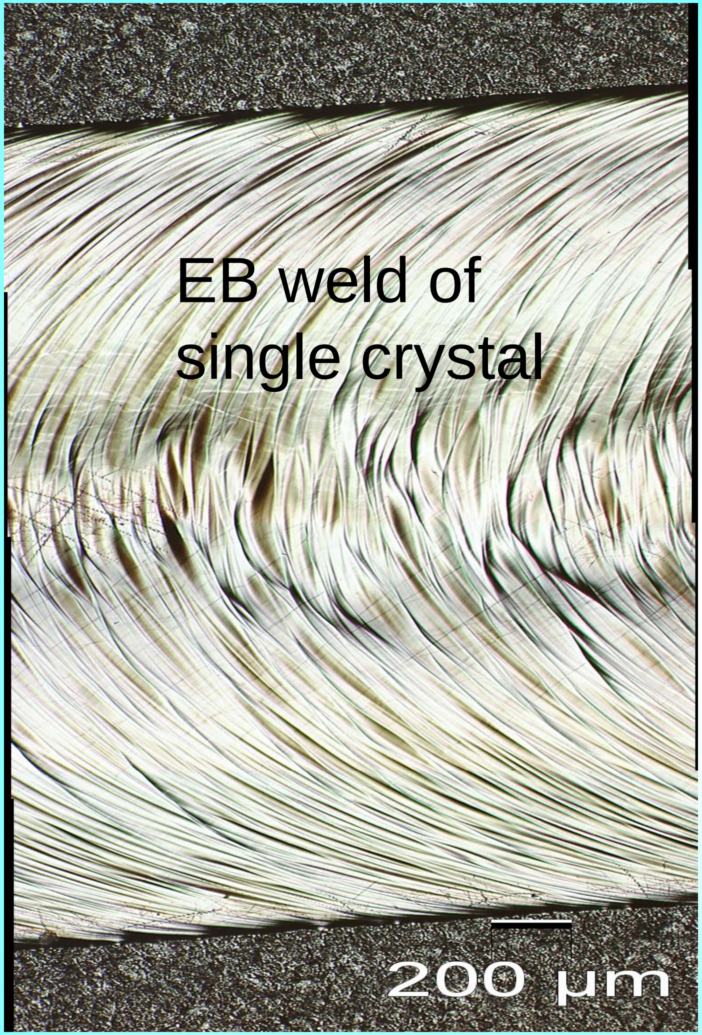
X-Ray is oriented perpendicular to the outside surface

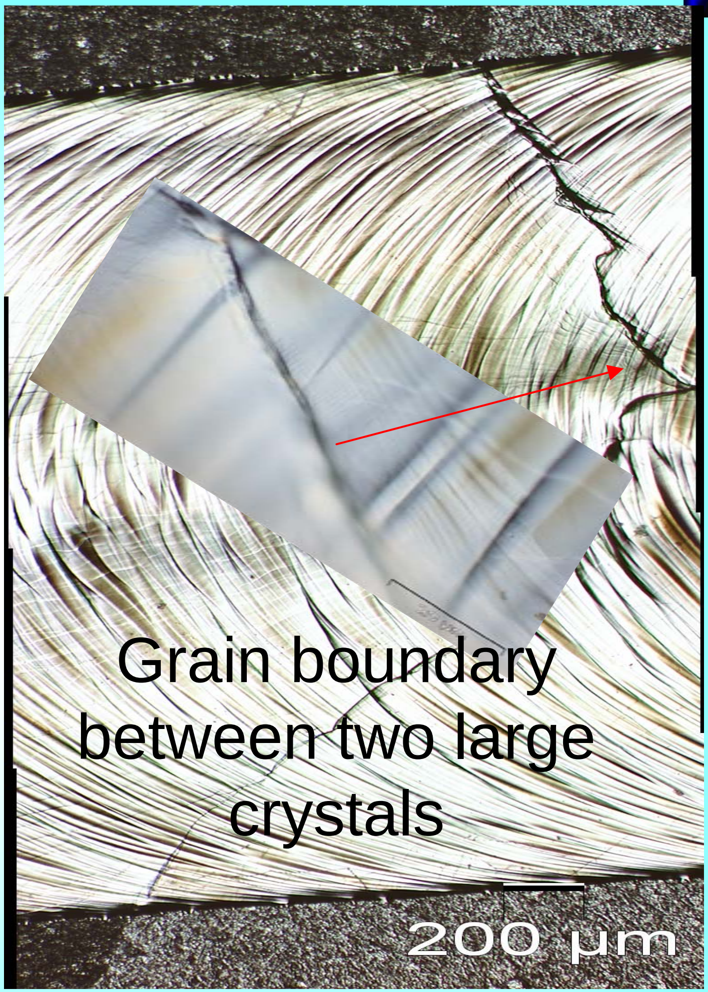


X-Ray reflexes of K1 on position 3 before (above) and after annealing at 800°C, 2hs

Determination of orientations of M. Spiwek (HASYLAB)

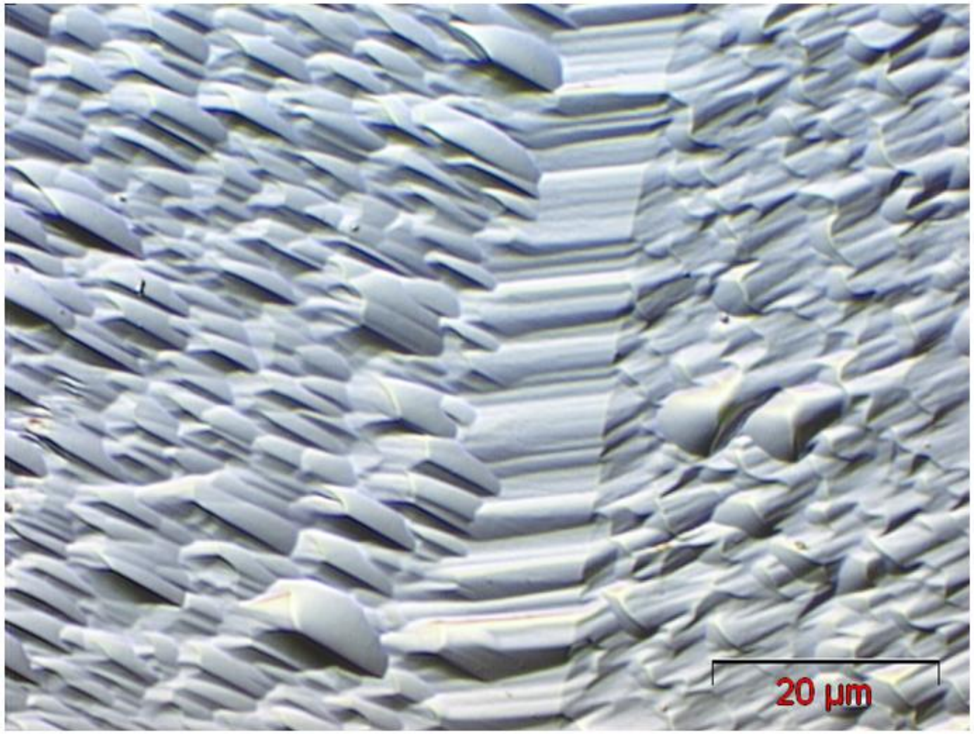
Electron beam welding



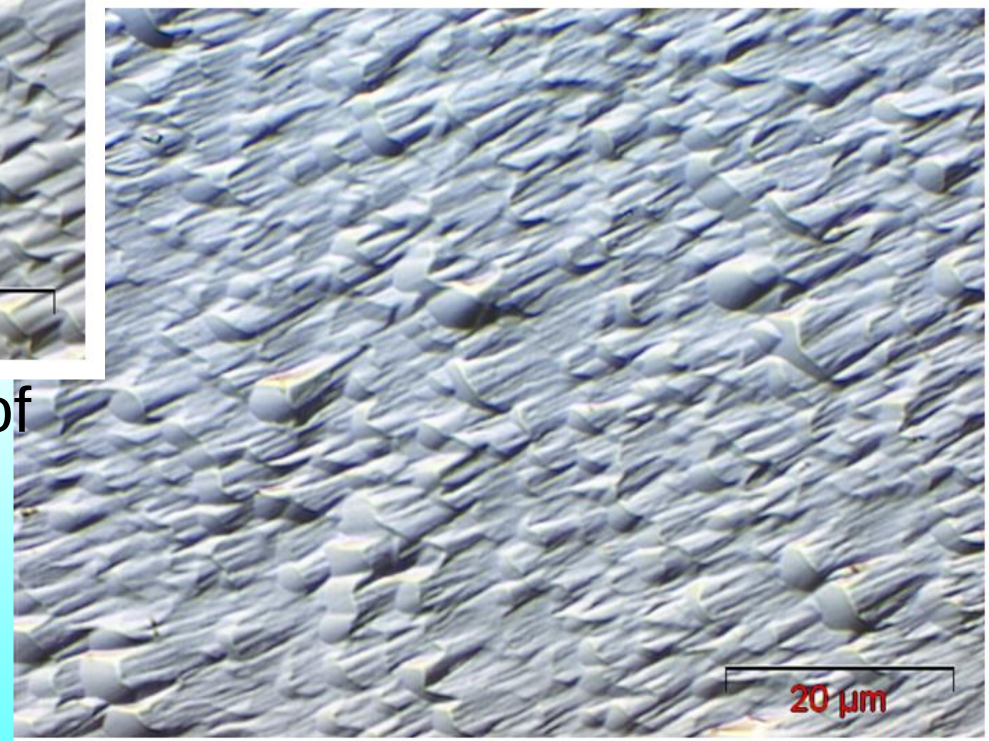


It seems that no new grains appear in the EB welding area, but the grain boundary remains

In the appropriate EB welding the single crystals can grow together

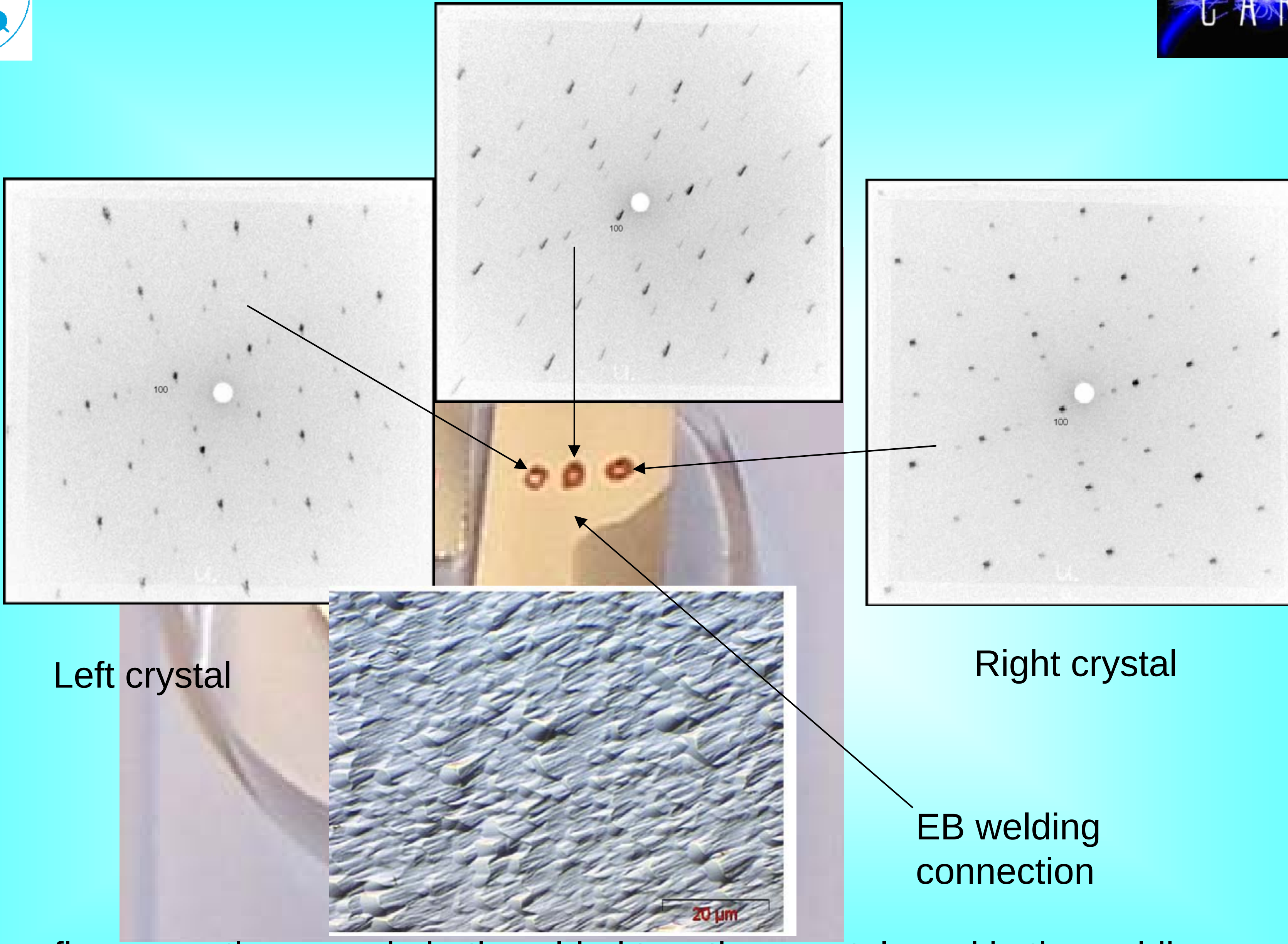


Left: Electron beam welding connection of two single crystals without regarding of crystals orientation (the grain boundary is pronounced)



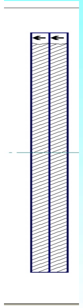
Right: EB welding connection of two single crystals after assembling considering the crystal orientation (the grain boundary is absent)

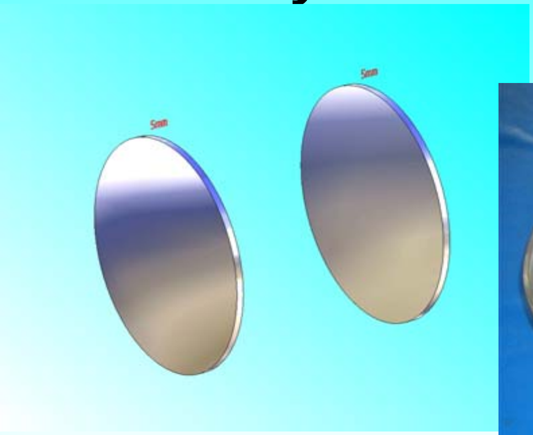
EB welding seam



X-Ray reflexes are the same in both welded together crystals and in the welding seam

Single crystal cavity fabrication

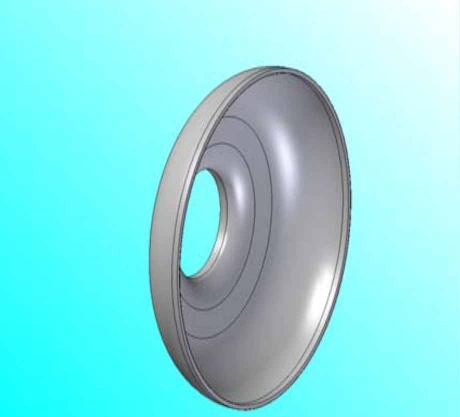




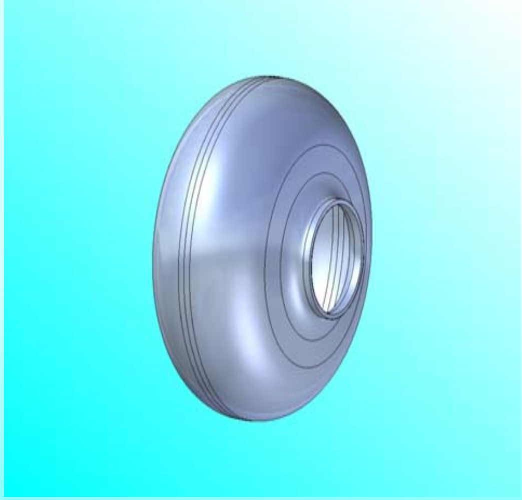
1. Take out central single crystal of definite thickness

2-3.Cutting through the disc and increasing of diameter by special rolling

Single crystals after deep drawing at ACCEL

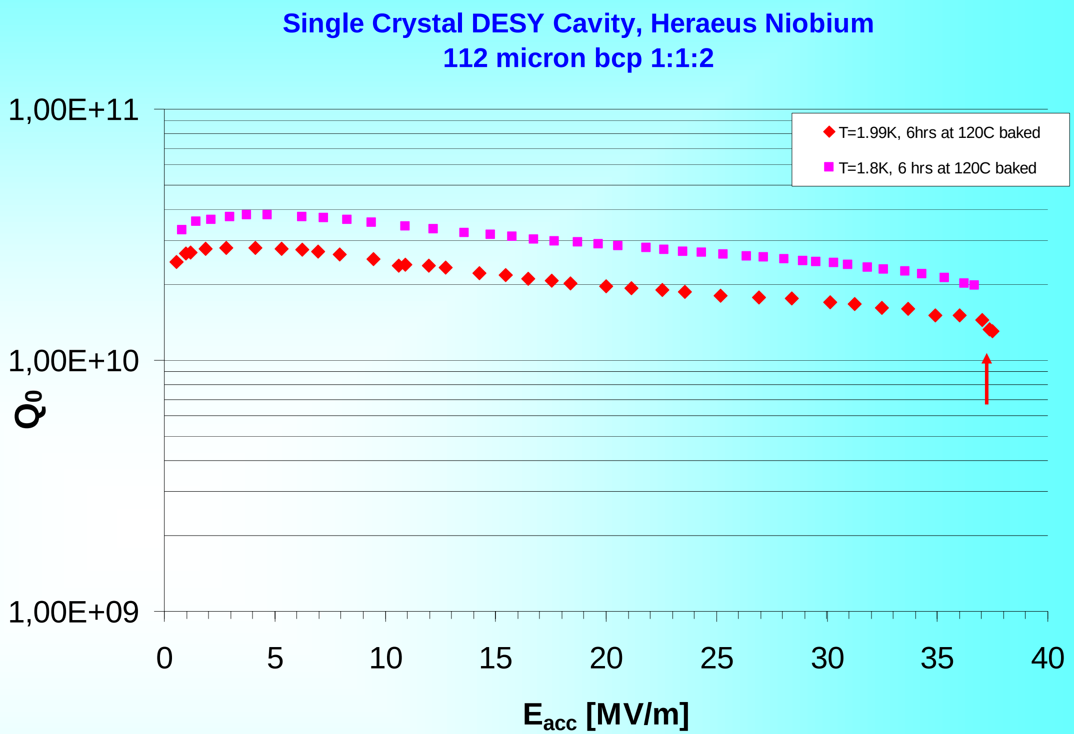


4. Deep drawing



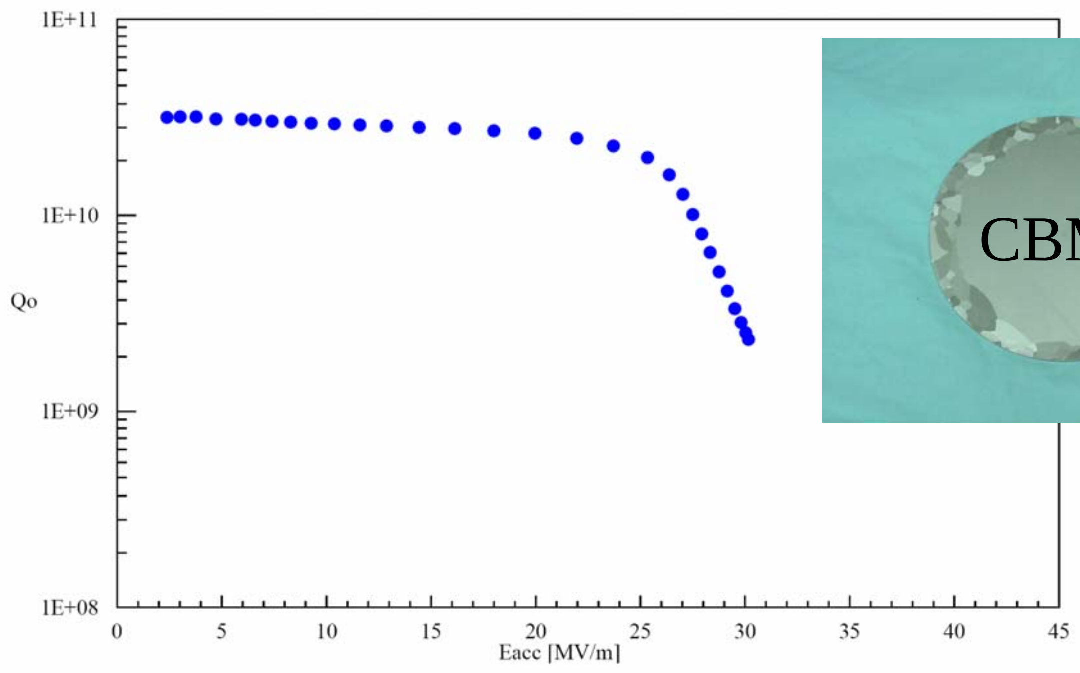
5. EB welding considering the crystal orientation

DESY single crystal cavity 1AC8 build from Heraeus disc by rolling at RWTH, deep drawing and EB welding at ACCEL



Q(Eacc) curve after only 112 µm BCP and in situ baking 120°C for 6 hrs.

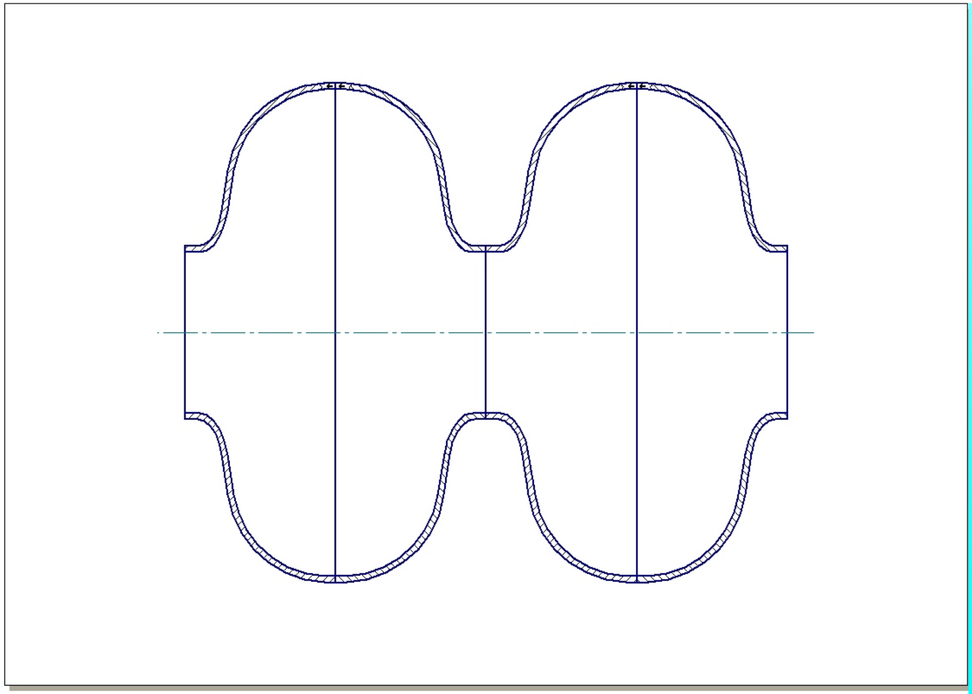
Preparation and RF tests of P.Kneisel, JLab

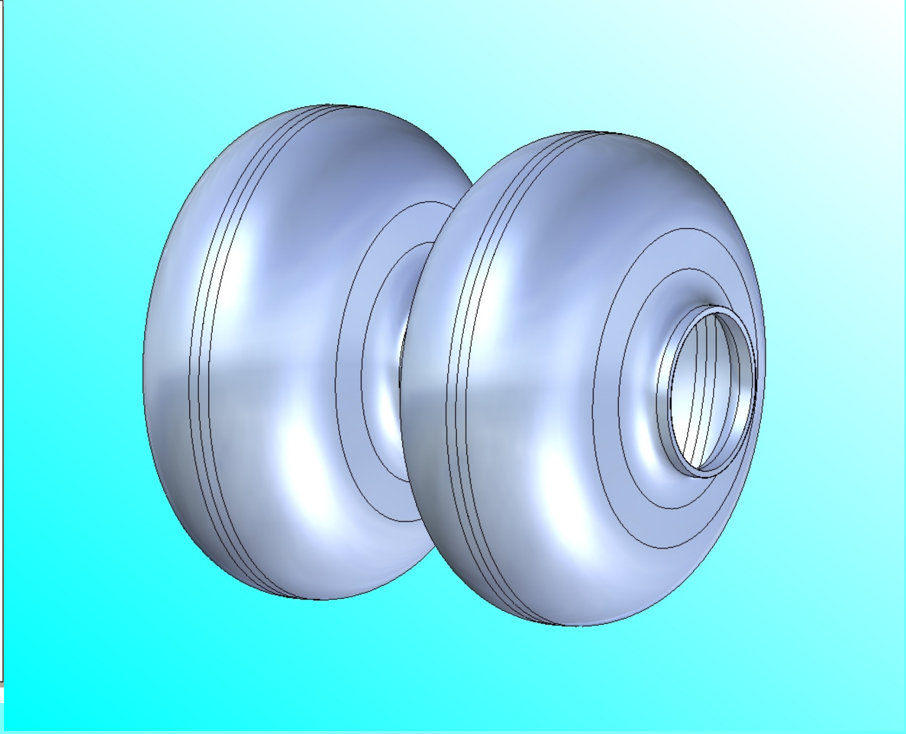


DESY single crystal cavity 1AC6; CBMM material, ca. 250 µm BCP, 100 µm EP at Henkel. X-Ray started at 24 MV/m. Limited by power

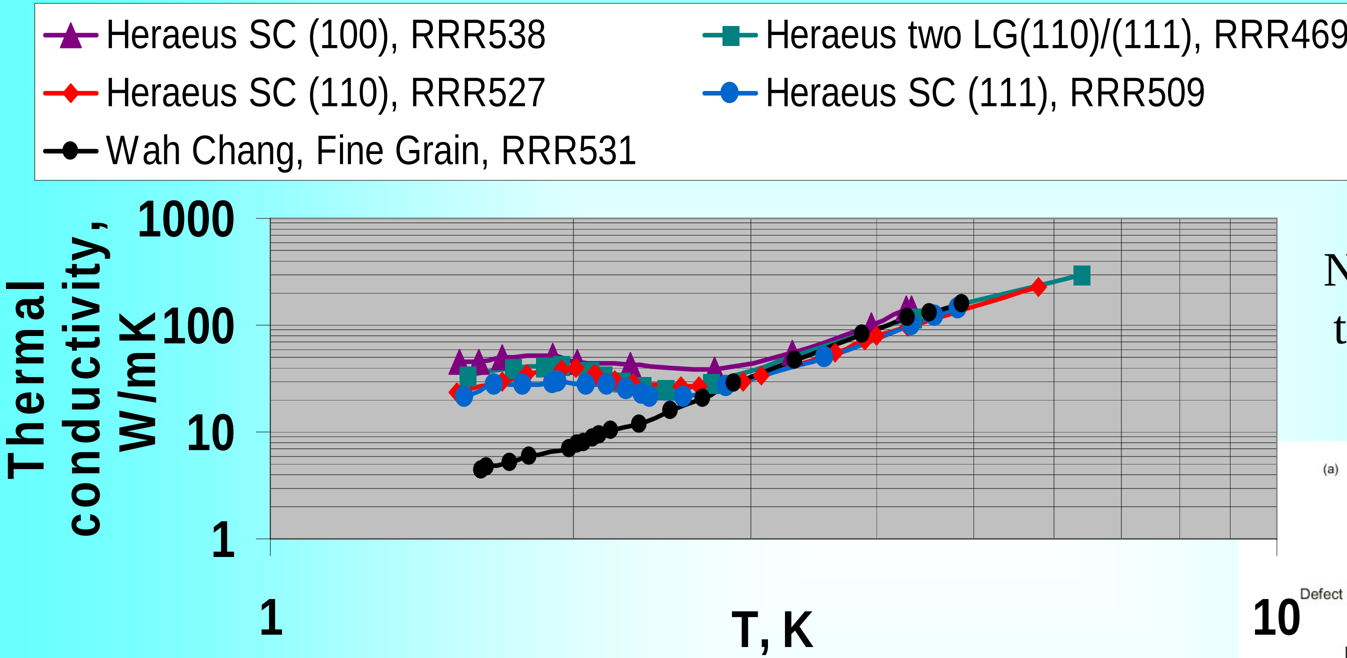
Single cell cavity 1AC6 fabricated by ACCEL (spinning and EB welding) from CBMM single crystal of diameter ca. 200 mm

SC. It works. The proposed method can be extended on fabrication of multi cell cavities.

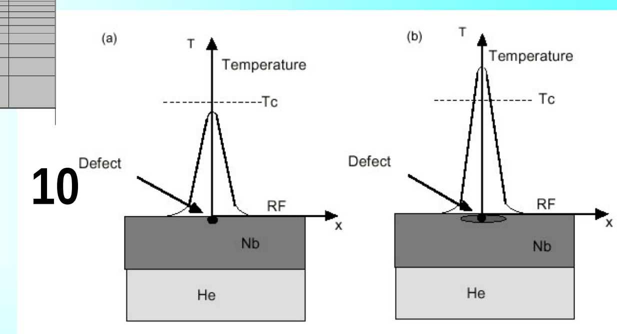




Material Investigation:
Thermal conductivity



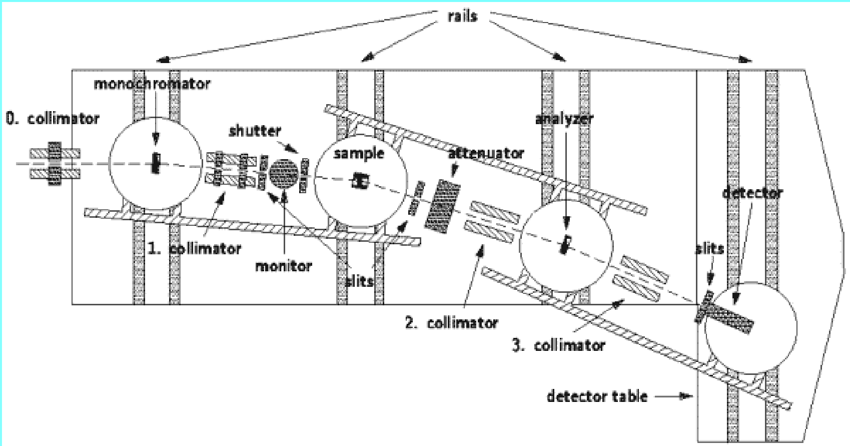
Normal conducting cluster triggers the quench, if the temperature exceeds Tc



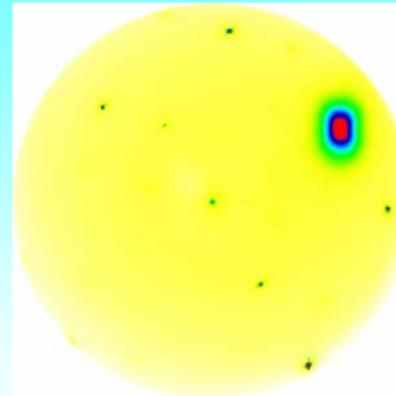
Thermal conductivity of single crystals in comparison with polycrystalline material. Phonon peak is clearly pronounced for single crystals.

$$\lambda(T,RRR,G)=R(y)\cdot\left[\frac{\rho_{295K}}{L\cdot RRR\cdot T}+a\cdot T^{2}\right]^{-1}+\left[\frac{1}{D\cdot\exp(y)\cdot T^{2}}+\frac{1}{B\cdot G\cdot T^{3}}\right]^{-1}$$

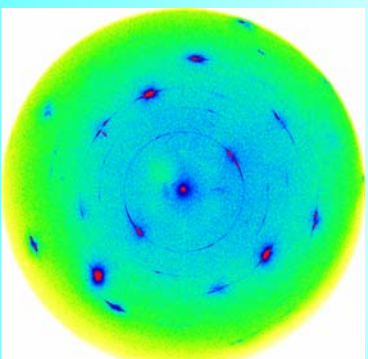
SC characterization (H.-G. Brokmeier)



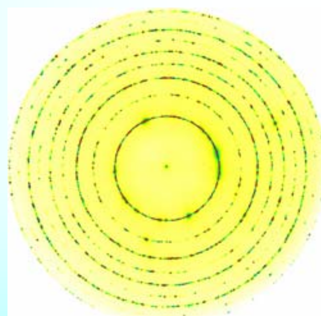
BW5 of DESY HASYLAB for X-ray penetration experiments at energies above 60 keV



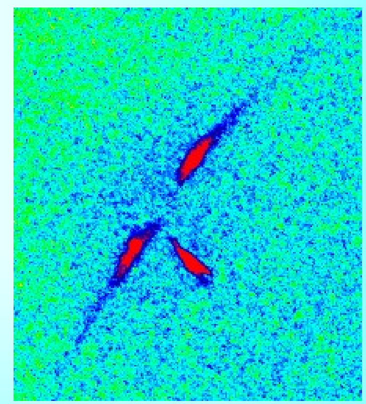
Strong SC signal. Real SC



Not real SC.



Powder X-Ray reflexes

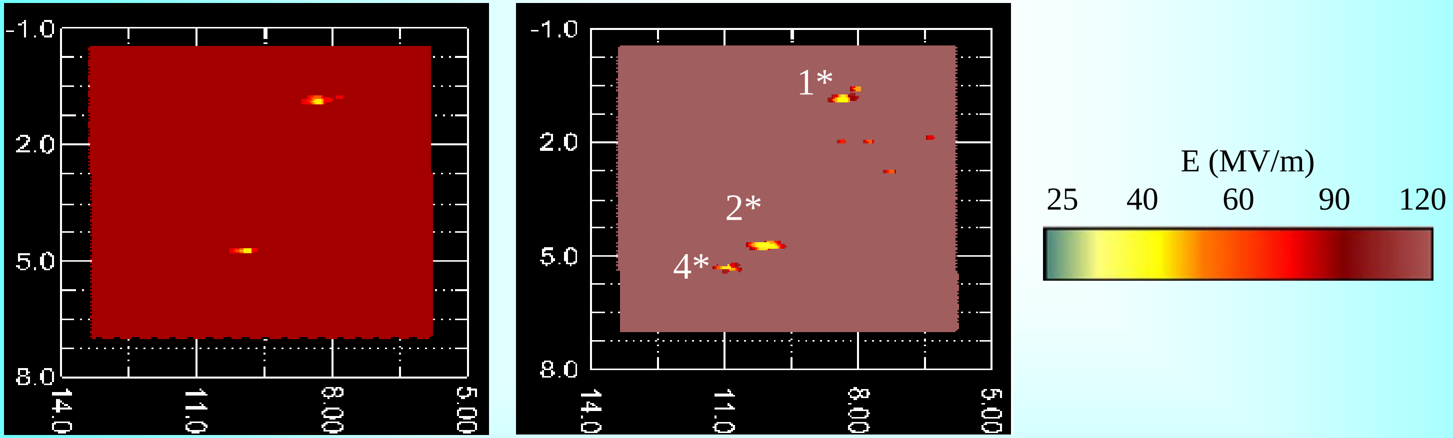


Signal splitting

Signal splitting of reflexes (indication for several single crystals) and Debye Scherrer rings (indication for the powder or small crystals material)

E = 120 MV/m, 0 emitters   E = 150 MV/m, 2 emitters   E = 200 MV/m, 4 emitters

FE scans on single crystal Nb sample after 30 µm BCP.



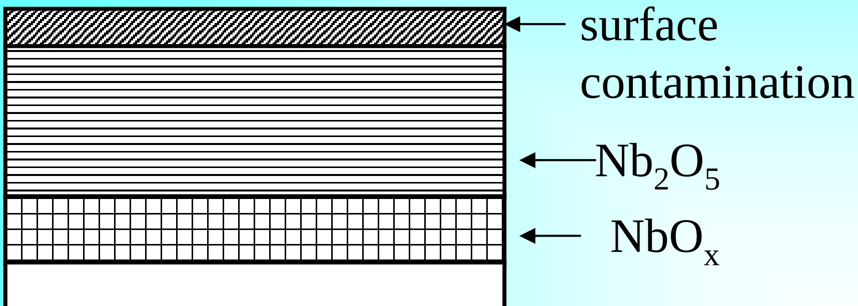
Example of similar FE scans on fine grain EP Nb sample. (left) E = 90 MV/m, 3 emitters (right) E = 120 MV/m, 8 emitters

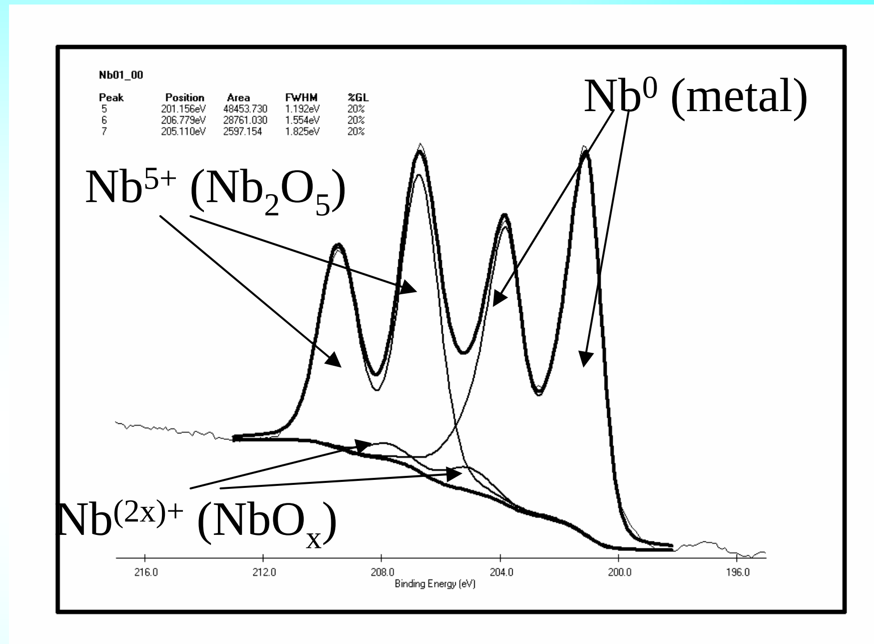
Field Emission Scanning: A.Dangwal, G.Mueller (Wuppertal)

Surface quality of the BCP treated SC is better as of EP treated polycrystalline Nb

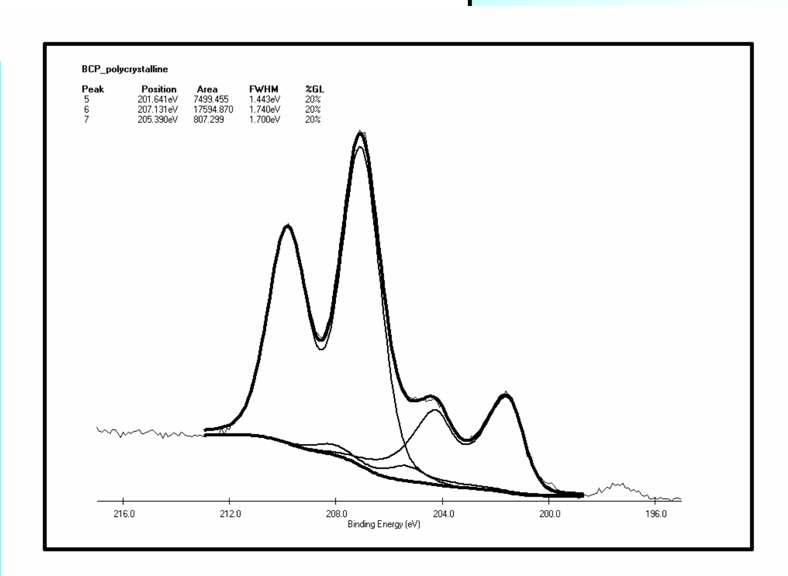
XPS on single crystal with different crystal orientation (preliminary results)

K.Kowalski, A.Bernasik (SSL, Krakow)





XPS spectrum for BCP single crystal Nb



XPS spectrum for BCP polycrystalline Nb

The oxide layer is thicker in polycrystalline Nb compare to single crystal

Conclusions

- Fabrication of single cell and multi cell cavities from large grain niobium by deep drawing and electron beam welding is feasible. Two aspects for fabrication are important: very desirable is to have only one large grain ca. 150 mm in the centre; desirable is to have only few large grain at the equator

- Accelerating gradient on the level of best fine grain cavities are achievable. A gradient up to 41 MV/m at $Q_0 = 1.4 \cdot 10^{10}$ (TB = 2K) was measured after EP. XFEL specification is reached on all three LG nine cell cavities after BCP treatment in first circle of preparation.

- Fabrication of single crystal cavities of ILC size is possible.

A lot of aspects of LG and SC have to be understand

- How to produce SCs of required dimensions ?
- What is the best crystal orientation for the best cavity performance (Hc1, Hc2, Hc3 dependence on crystal orientation)?
- Is the baking phenomena for SCs and LG different compare to polycrystalline material?
- Are the SCs surfaces oxides different compare to polycrystalline Nb and depend on the crystal orientation of the niobium substrate?
- Is higher onset of field emission for LG and SCs caused only by smooth surface or the mechanism is more sophisticated?
- Grain boundary of LG niobium. What is the difference between EP treated and BCP treated GB.
- Mechanical properties. Difference between one dimensional and two dimensional deformation?
- What are the exact conditions allowing to connect two SCs in one SC by EB welding and where is the limitation?
- What maximal deformation degree can tolerate the SCs and what is the optimal heat treatment for SCs?

Proposal: Extension of the Single Cell Cavity Program (EB welding at DESY) W.Singer 28.11.06

Material	Aim	No. of Cav.	Req. End tubes	Req. Flanges	Reg. Halte-Ringe	Status
Standard/PC	Check of the improved DESY fabrication procedure, R&D	7	14	14	28	Sheets available
Standard/PC	EP R&D	3	6	6	12	Sheets available
HERAEUS/SC	Qualification of the procedure. Testing of new ingots	3	6	6	12	Shipment of discs 2007
CBMM/SC/LG	Qualification of the Fa. (RRR>300)	3	6	6	12	In negotiation, (possibly 07)
Ningxia (China)/SC ???	Qualification of the procedure	3	6	6	12	In negotiation, (possibly 07)
ITEP_ZMP (Russia)/PC/LG ???	Qualification of the Fa. (ILC, possibly XFEL)	3	6	6	12	Order in 2007
Sum		22	44	44	88	

PC-Polycrystalline; LG- Large Grain; SC-Single Crystal