Past, Present and Future Prospects of SRF Ingot Niobium Technology

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10^{-7} cm
International Symposium on
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Past - ingot niobium SRF technology

FIG. 1. An electron-beam welded TM_{010} mode Nb cavity. The cavity is resonant at 8.6 GHz and is 3.6 cm in overall length.

B_{pk}~ 108 mT with BCP
After 1800° C heat treatment

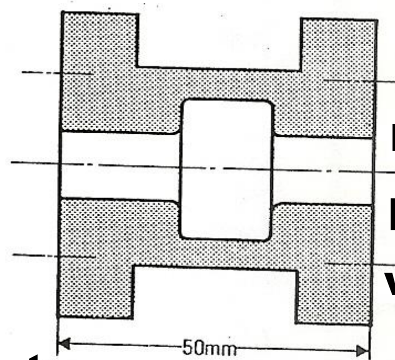


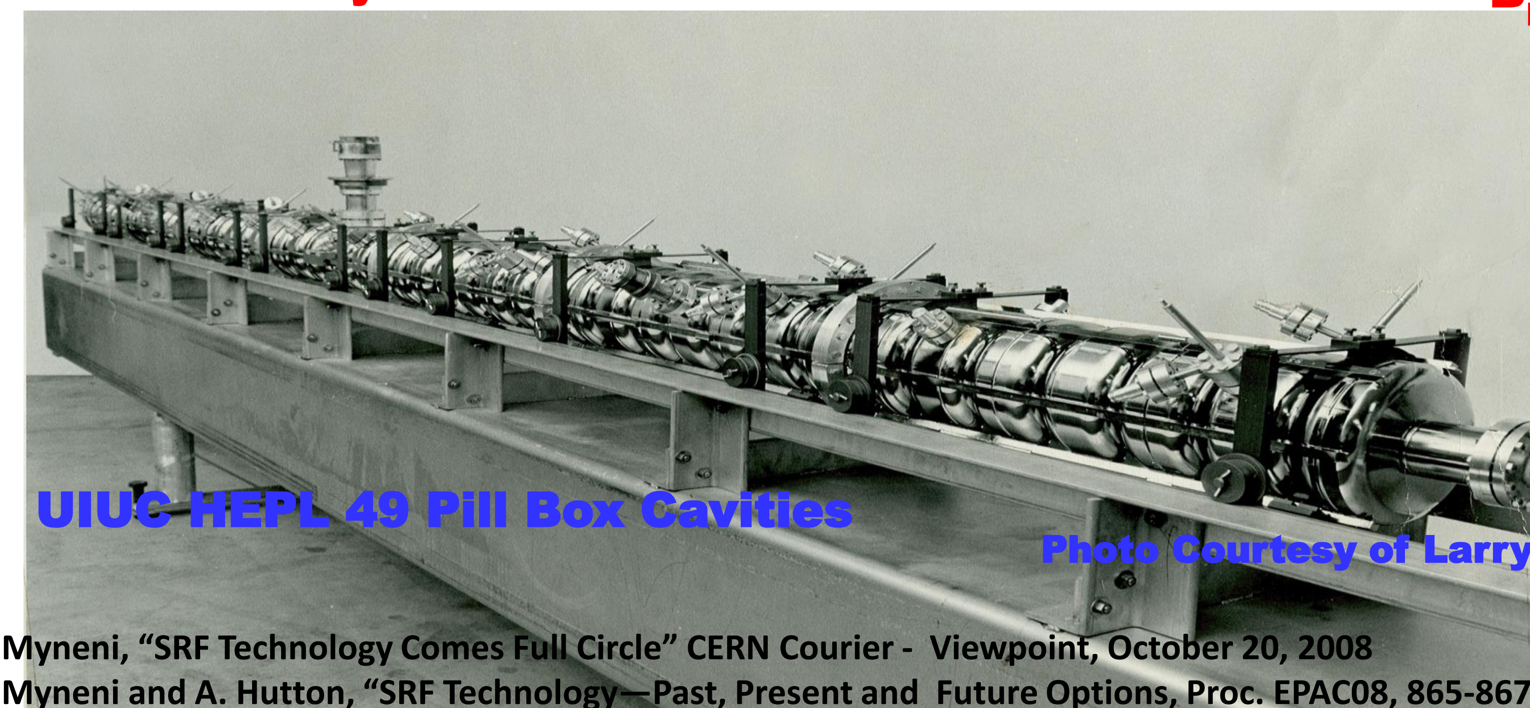
Fig. 1. Single piece TM_{010}-niobium cavity with a resonant frequency of 9.5 GHz.

B_{pk}~ 109 mT with BCP

B_{pk}~ 130 mT with EP with heat treatments

Note:
B_{pk} ~ 159 mT with EP for reactor grade polycrystalline cavity - no heat treatment

B_{pk}/E_{acc} ~ 3



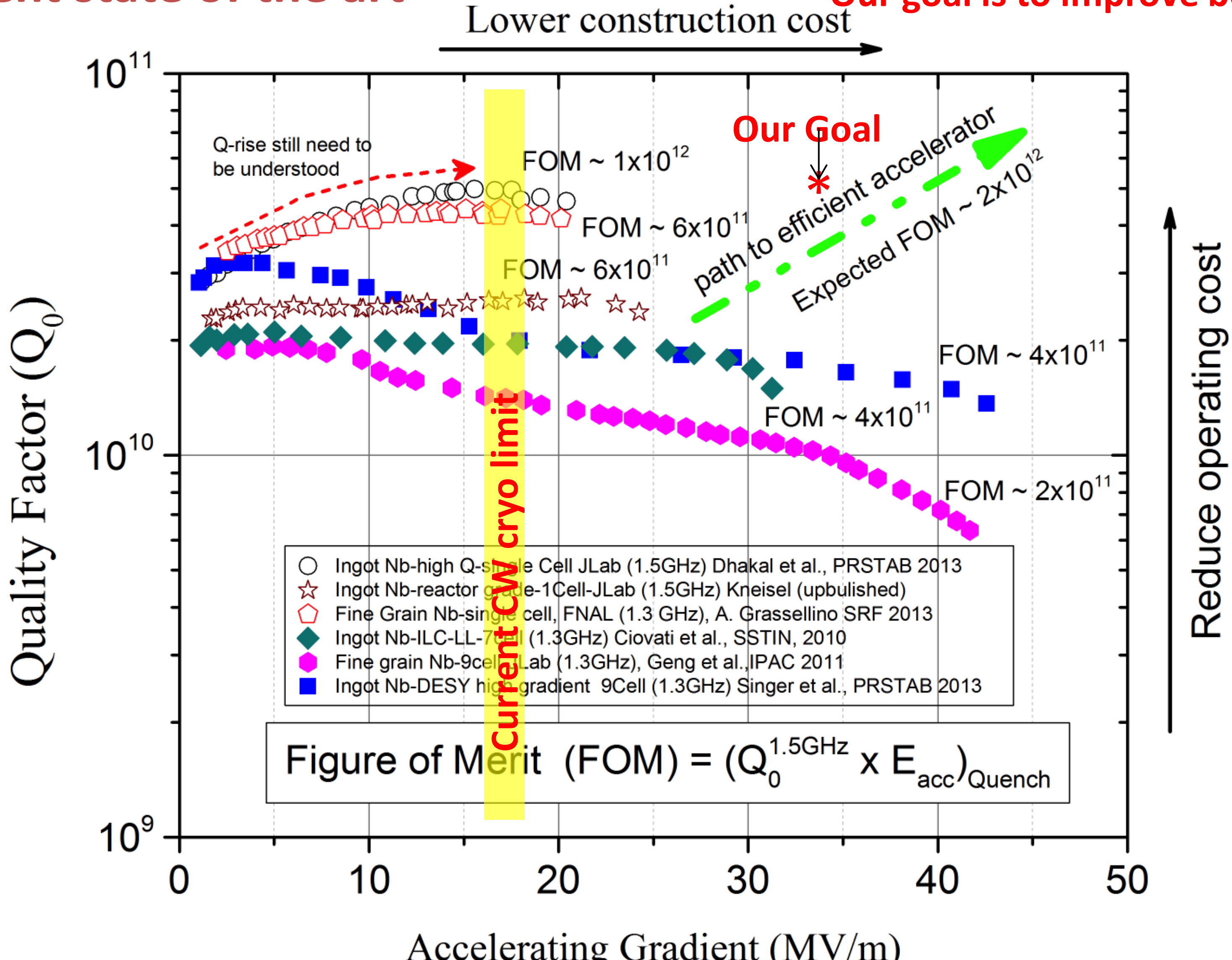
UIUC HEPL 49 Pill Box Cavities

Photo Courtesy of Larry Cardman

G. R. Myneni, “SRF Technology Comes Full Circle” CERN Courier - Viewpoint, October 20, 2008
G. R. Myneni and A. Hutton, “SRF Technology—Past, Present and Future Options, Proc. EPAC08, 865-867, 2008

Present state of the art

Our goal is to improve both Q_0 and E_{acc}



Ingot niobium Rs is low and phonon peak improves thermal stability

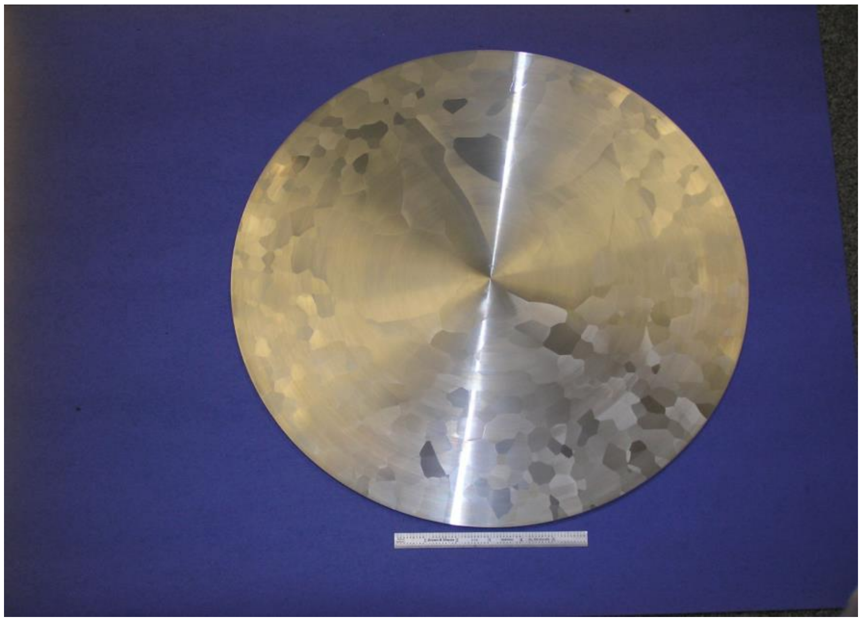
Review of ingot niobium as a material for superconducting radio frequency accelerating cavities
P. Kneisel, G. Ciovati, P. Dhakal, K. Saito, W. Singer, X, Singer, G. R. Myneni
Nuclear Instruments and Methods in Physics Research A 774 (2015) 133-150

Technical specifications of niobium for future SRF linacs

Material parameter	TESLA/XFEL Pulsed/CW	CW/Pulsed SRF Linac (proposed)
Type	Polycrystalline	Ingot Slices
RRR	> 300	50 - 200
Grain Size	~ 50 µm	> 1 cm
Yield Strength	> 50 N/mm^2	> 50 N/mm^2
Tensile Strength	> 100 N/mm^2	> 100 N/mm^2
Elongation	30%	30%
Contents of the Impurities wt. ppm	Ta ≤ 500 O ≤ 10 N ≤ 10 C ≤ 10 H ≤ 2	Ta ≤ 1300
Vickers Hardness	≤ 60	~ 50

Note: the interstitials content is not specified here for the ingot SRF cavities since the Vickers hardness already defines the interstitial content

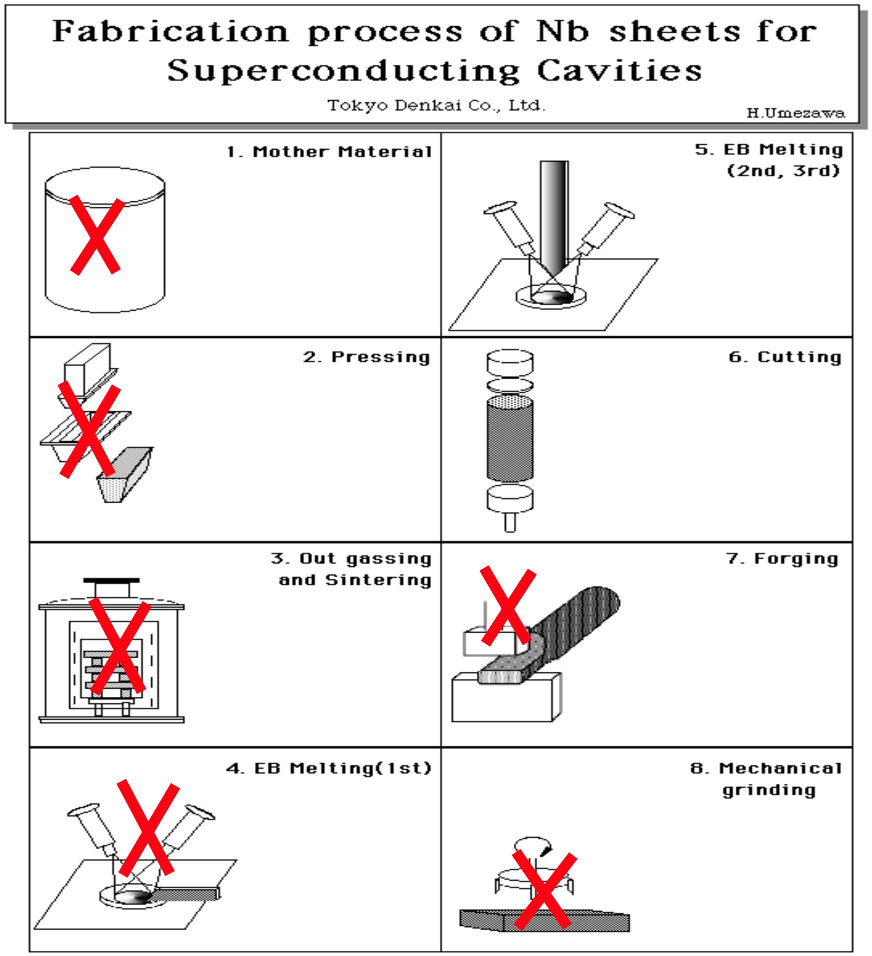
Uniform grain reactor grade ingot niobium technology

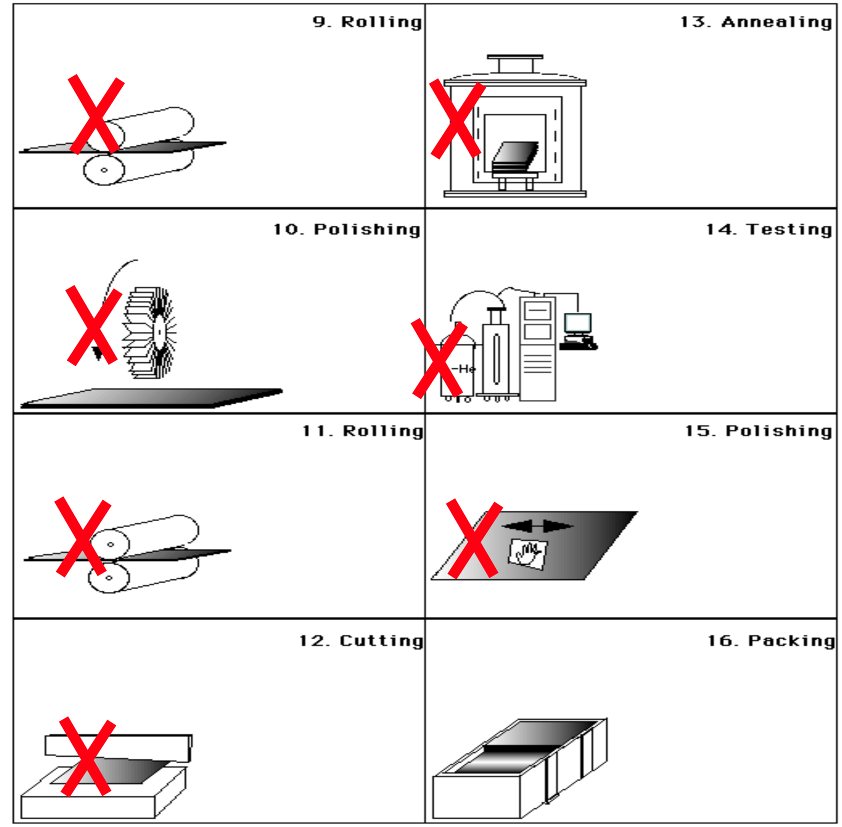


Reactor grade ingot niobium slice (Wah Chang)

BNL ingot niobium gun cavity (Courtesy AES)

Economic, efficient and sustainable path for CW applications





Note:
Cost of the ingot sliced Nb sheets anticipated to be less than 1/4th of polycrystalline Nb & no QA

Expected material cost savings at least 50%

Intrinsic contamination of Nb with hydrogen & proton-dislocation interaction appear to determine the performance of the cavities

- Niobium is a prolific hydrogen absorber in the absence of the natural surface oxide*
  - Hydride formation
  - Dislocations-proton interaction

*R.E. Ricker, G. R. Myneni, J. Res. Natl. Inst. Stand. Technol. 115, 353-371 (2010)

D. Richter, R. J. Rush and J. M. Rowe, “Localized modes and hydrogen trapping in niobium with substitutional impurities,” Phys. Rev. B 27 (1983), pp.6227-6233.

G. Pfeifer and H. Wipf, “the trapping of hydrogen in niobium by nitrogen interstitials,” J. Phys. F: Metal Phys., Vol 6, No. 2 (1976), pp 167-179.

Ingot niobium SRF technology for sustainability

High quality factor with simple process-procedures

- **Lower flux trapping**
- **High thermal conductivity at the operating temperature (Phonon peak)**
- **Low residual resistance**

Inexpensive

- **A factor of 3 to 4 lower than high purity fine grain niobium**
- **Minimum processes – no need for QA**
- **No alloying with nitrogen required**

Future Prospects

- **Ingot niobium technology (low RRR, high tantalum content) would be ideal for SRF applications**

- **We expect that this technology will be the preferred choice for future superconducting linacs world-wide**

- **Several Labs from the three continents are discussing a joint program to optimize the ingot niobium multi cell cavity processes for high efficiency & high intensity linac applications**

10^{-7} cm

International Symposium on
Hydrogen in Matter (ISOHIM)

July 30 – Aug 1, 2014
India

S-VYASA University
Bengaluru

4th International Symposium On Hydrogen-Matter Interactions

The deliberations at the three day symposium include hydrogen-matter interactions effects on:

- **Physical & mechanical properties of materials**
- **Energy transfer systems**
- **Biological processes & human health etc.**

Multi disciplinary experts from around the world will exchange ideas, examine synergies and forge collaborations to further the scientific understanding of Hydrogen-Matter interactions.

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Experts from around the world will exchange information on topics relevant to accelerator-driven sub-critical systems.

The three-day workshop includes five working sessions:

- Fast spectrum and thorium-based systems
- Thermal spectrum systems
- Comparison to other systems and future directions
- Superconducting radio frequency ingot niobium technology
- Accelerator systems and enabling technologies

The workshop will seek to identify areas of common interest to explore the possibilities of future collaboration.

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International Symposium On Hydrogen In Matter (ISOHIM) Publications

Hydrogen in Materials and Vacuum Systems AIP CP 671
http://www.virtualjournals.org/dbt/dbt.jsp?KEY=APCPCS&Volume=671&Issue=1

Hydrogen in Matter AIP CP 837
http://www.virtualjournals.org/dbt/dbt.jsp?KEY=APCPCS&Volume=837&Issue=1

Single Crystal Large Grain Niobium AIP CP 927
http://www.virtualjournals.org/dbt/dbt.jsp?KEY=APCPCS&Volume=927&Issue=1

Superconducting Science and Technology of Ingot Niobium AIP CP 1352
http://scitation.aip.org/dbt/dbt.jsp?KEY=APCPCS&Volume=1352&Issue=1

Science and Technology of Ingot Niobium for Superconducting Radio Frequecy Applications to be released Dec 2015

Worldwide network of collaborators

Tadeu Carneiro, Rogerio Ribas, Marcos Stuart – CBMM	ingot niobium technology
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J. Wallace – Casting Analysis Corporation	co-PI DOE ONP ARRA Q_0 improvement program
Björgvin Hjörvarsson – Uppsala University	hydrogen-niobium system
B. Lanford – UNY, Albany	nuclear reaction analysis
R. Pike and summer student interns – W&M	XRD analysis of niobium
Hani Elsayed-Ali, Ashraf Hassan Farha (grad student) – ODU	niobium nitride
Asavari Dhavale & J. Mondal (grad students) – BARC/HBNI	ingot niobium properties
Sindhunil Roy – RRCAT	SC properties of niobium
Saravan Chandrasekaran – MSU	ingot niobium properties
International Symposium On Hydrogen In Matter (ISOHIM)	non profit organization for education/training

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