Forged Ingot Niobium Technology for Scientific Frontiers and Accelerator Applications

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Jefferson Lab KEK BSCE SYSTEMS, INC. ATI U.S. DEPARTMENT OF ENERGY Office of Science JSA

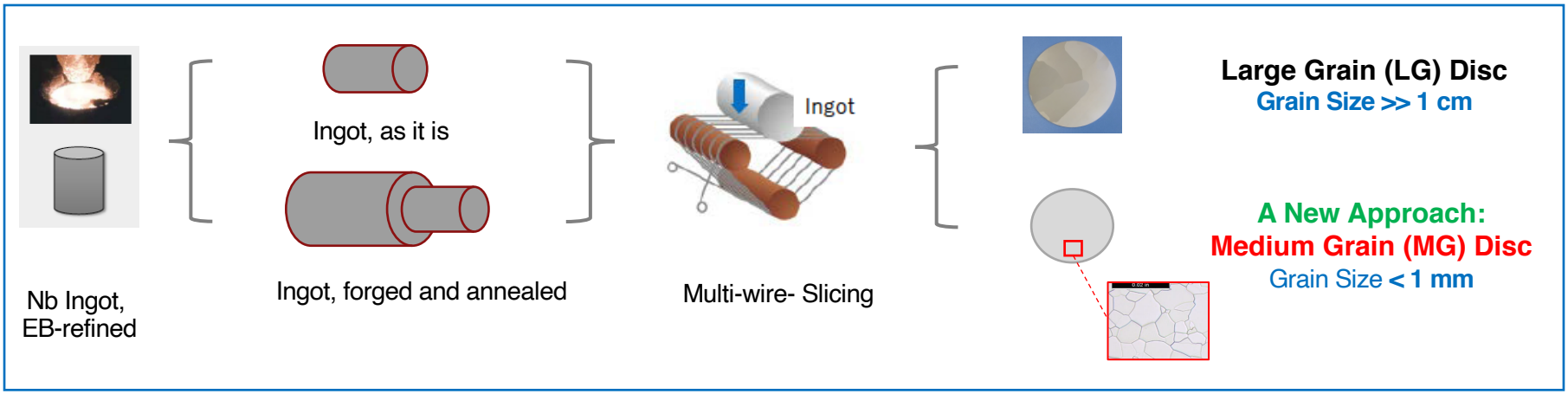
Intro to Nb Technologies for SRF

Fine Grain (FG) Rolled Nb sheets	Medium Grain (MG) Forged Ingot Nb discs	Large Grain (LG) Ingot Nb discs
Up to fourteen manufacturing steps Labor intensive	E-beam melted ingot of larger dia. forged to required dia and then sliced	E-beam melted ingot of required dia. is sliced
Grain Size ASTM 5 ~ 50 µm	ASTM 0 – 3, < 1 mm	Large non uniform grains >1 cm
Widely used complex technology prone to contamination	New kid on the block and very clean surfaces	Proven clean surface technology
Uniform & adequate mechanical properties	Superior uniform mechanical properties	Non uniform mechanical properties
Requires stringent QA & expensive	Cost advantage	Cost advantage

Courtesy: ATI

Medium Grain Nb discs sliced from Nb Forged Ingot*

- Aiming for clean, mechanically stable, and cost-effective SRF cavity production.

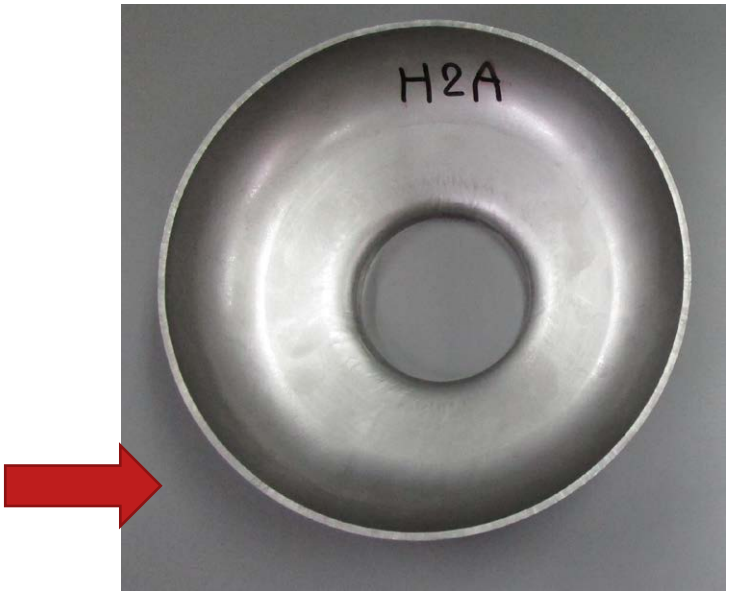


* The "Nb forged ingot" technology originated by **ATI** (see Appendix), and SRF (GHz) cavities planned to be fabricated and RF tested by **KEK** and **JLab**, to qualify this approach, in the collaboration of **ATI, BSCE, JLab, ODU and KEK.**

A Sample Half-cell successfully press formed,
using a Disc sliced from Nb Forged Ingot
in cooperation of ATI, BSCE and KEK

- A sample/trial MG disc directly sliced from Nb forged ingot pre-produced by **ATI**
  - RRR; ~ 100,
  - Grain-size: ASTM 3.5 ~ 5.5,
  - Thickness 3.1 mm,
  - Heat-treated,

- The disc press-formed, as a practice at **KEK**, with **successfully** keeping good mechanical stability.



KEK

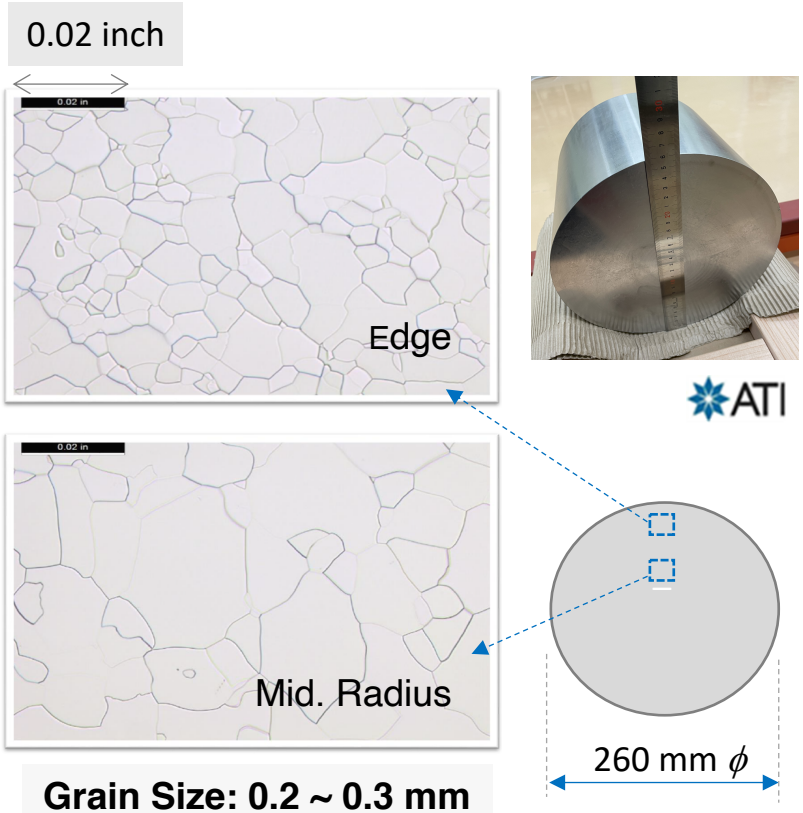
Courtesy: ATI

Sample Nb-RRR Forged Ingot produced by ATI for 1.3 GHz SRF cavity fabrication at KEK

"**Nb RRR**" Billet, annealed

Sample location

Parameters	Nb sheet (FG) (Spec. Eu-XFEL as Reference)	Nb forged ingot (MG) Measured
RRR	$R_{RT}/R_{4.2K}$ ≥ 300	R_{RT}/R_{TC} 450 523
Re-crystallization	100 %	100 %
Grain size (ASTM) Edge, Mid., Center	4 ~ 6	2 , 1, 1.5
Grain size (mm) Edge, Mid.,Center	< 0.05	0.2, 0.25, 0.21
Y.S.-0.2% (RT)	≥ 50 MPa	61 MPa
T.S. (RT)	≥ 140 MPa	141 MPa

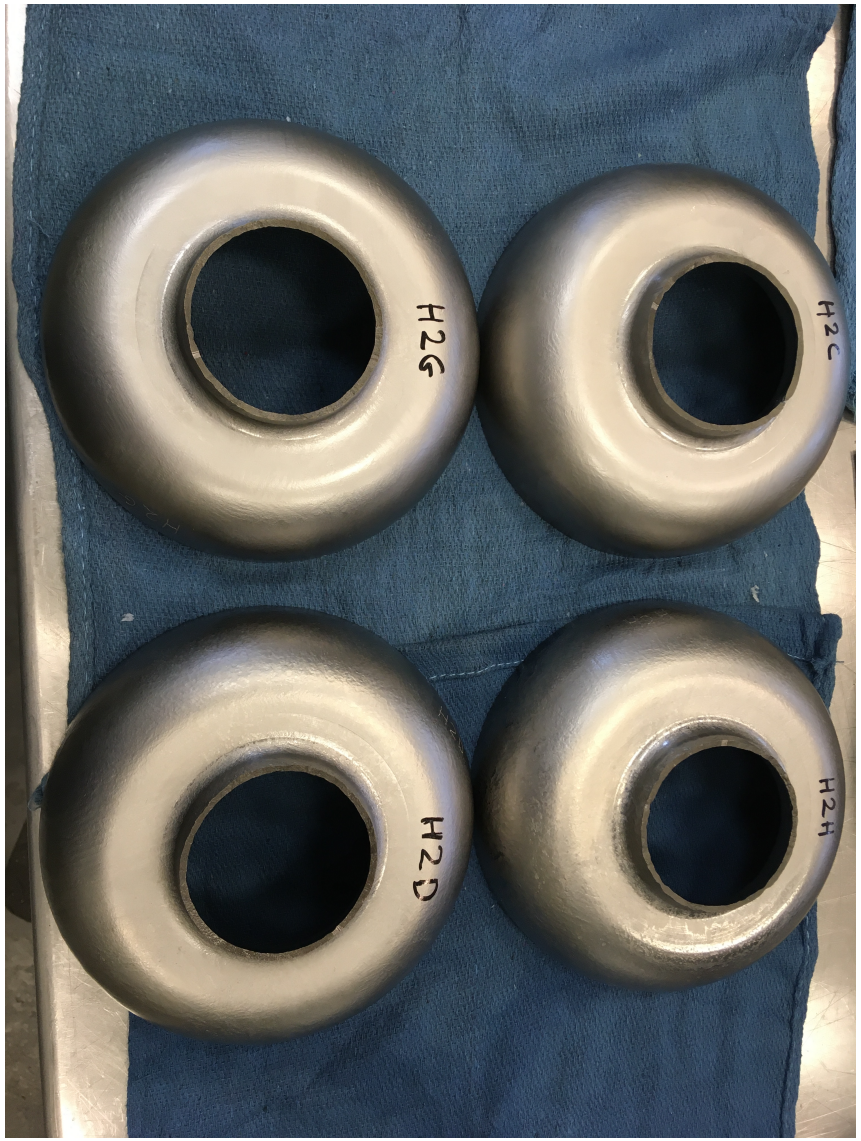


Grain Size: 0.2 ~ 0.3 mm
Mechanical stability may be expected

C75 Single and Multicell MG Cavities with NbGr1

- Jefferson Lab is in the process of fabricating single C75 cavities
- NbGr1 forged ingot Nb discs are being produced by ATI for multicell C75 cavities fabrication at Jefferson Lab
- The C75 MG Nb Technology is being planned to be industrialized for a wide range of Accelerator Applications

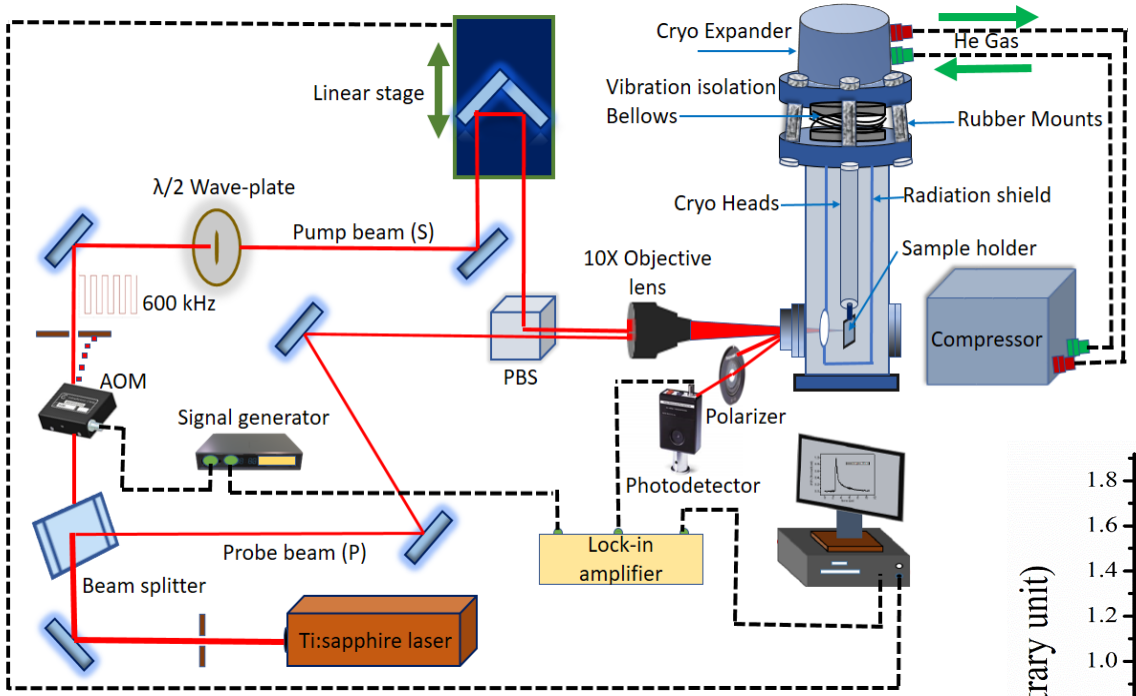
Forged Nb Ingot JLab C75 half cells



Comparison of NbGr1 & RRR Nb

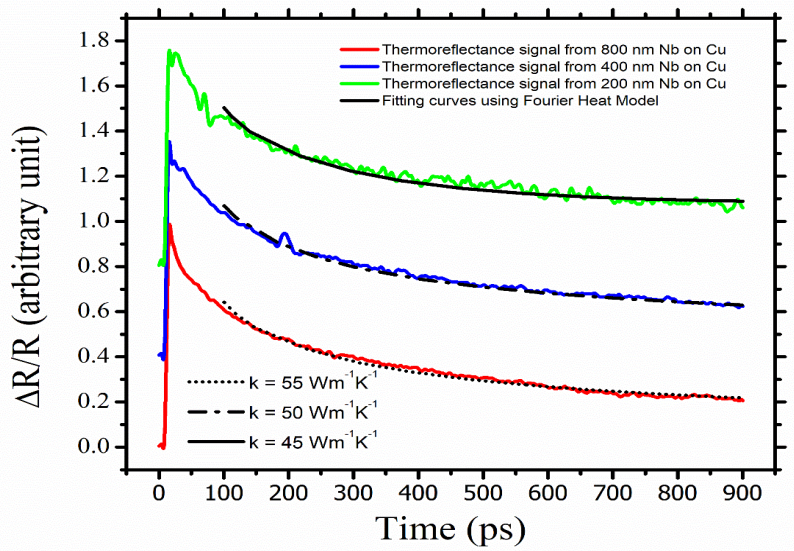
Parameters	Nb Gr1 (MG) Measured	RRR Nb (MG) Measured
RRR	~ 100	450 523
Re-crystalization	100 %	100 %
Grain size (ASTM) Edge, Mid., Center	0.5 - 5	2 , 1, 1.5
Grain size (mm) Edge, Mid., Center	0.05 - 0.3	0.2, 0.25, 0.21
Y.S.-0.2% (RT)	~ 67 MPa	61 MPa
T.S. (RT)	> 147 MPa	141 MPa

Transient thermoreflectance measurement of the thermal conductivity of 200-800 nm Nb film on Cu



$$C\frac{\partial T_{(x,t)}}{\partial t} = -k\frac{\partial^2 T_{(x,t)}}{\partial x^2}) + S(x,t)$$

$T(x,t)$ temperature profile, x distance normal to the film surface, C heat capacity per unit volume, k thermal conductivity and $S(x,t)$ laser source term.



Transient thermoreflectance from Nb films on Cu with three different thicknesses: 200 nm Nb fitted with k = 45 $Wm^{-1}K^{-1}$, 400 nm Nb fitted with k = 50 $Wm^{-1}K^{-1}$ and 800 nm Nb fitted with k = 55 $Wm^{-1}K^{-1}$. Curves for 200 and 400 nm are shifted for clarity. All measurement at RT.

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This technique will be used for measuring the Thermal diffusivity of MG Niobium

Summary

- Comparison of FG, MG and LG Nb Technologies
- MG RRR Nb Ingot is produced by ATI and shipped to KEK
- KEK will fabricate and qualify 1.3-GHz SRF cavities
- JLab plans to industrialize MG C75 technology for accelerator applications

Appendix:
Specialty Alloys & Components:
Innovator in reactive and refractory metals

ATI Specialty Alloys and Components began innovating specialty alloys more than 50 years ago and continues to lead the way with a wide range of specialty alloys in conventional product forms, as well as custom shapes and near-net shape components made possible by advanced finishing and machining operations.

Applications	Products	Capabilities
• Aerospace • Chemical Processing • Defense • Electronics and Catalysts • Electrical Energy • Jet Engine • Maritime • Medical • Missile & Space • Nuclear • Oil & Gas • Structural Components • Superconductivity	• NiTi Alloys • Hafnium • Niobium • OmegaBond® Tubing • Tantalum • Titanium • Tube-Reduced Extrusions (TREX) • Tungsten • Vanadium • Zirconium	• Finishing • Laboratory • Subassembly • Precision machining • Sonic configuration machining

ATI Specialty Alloys & Components Snapshot

Facilities in:
- Huntsville, AL
- Albany, OR