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QUALIFICATION OF LCLS-II PRODUCTION NIOBIUM MATERIAL INCLUDING RF AND FLUX EXPULSION MEASUREMENTS ON SINGLE-CELL CAVITIES

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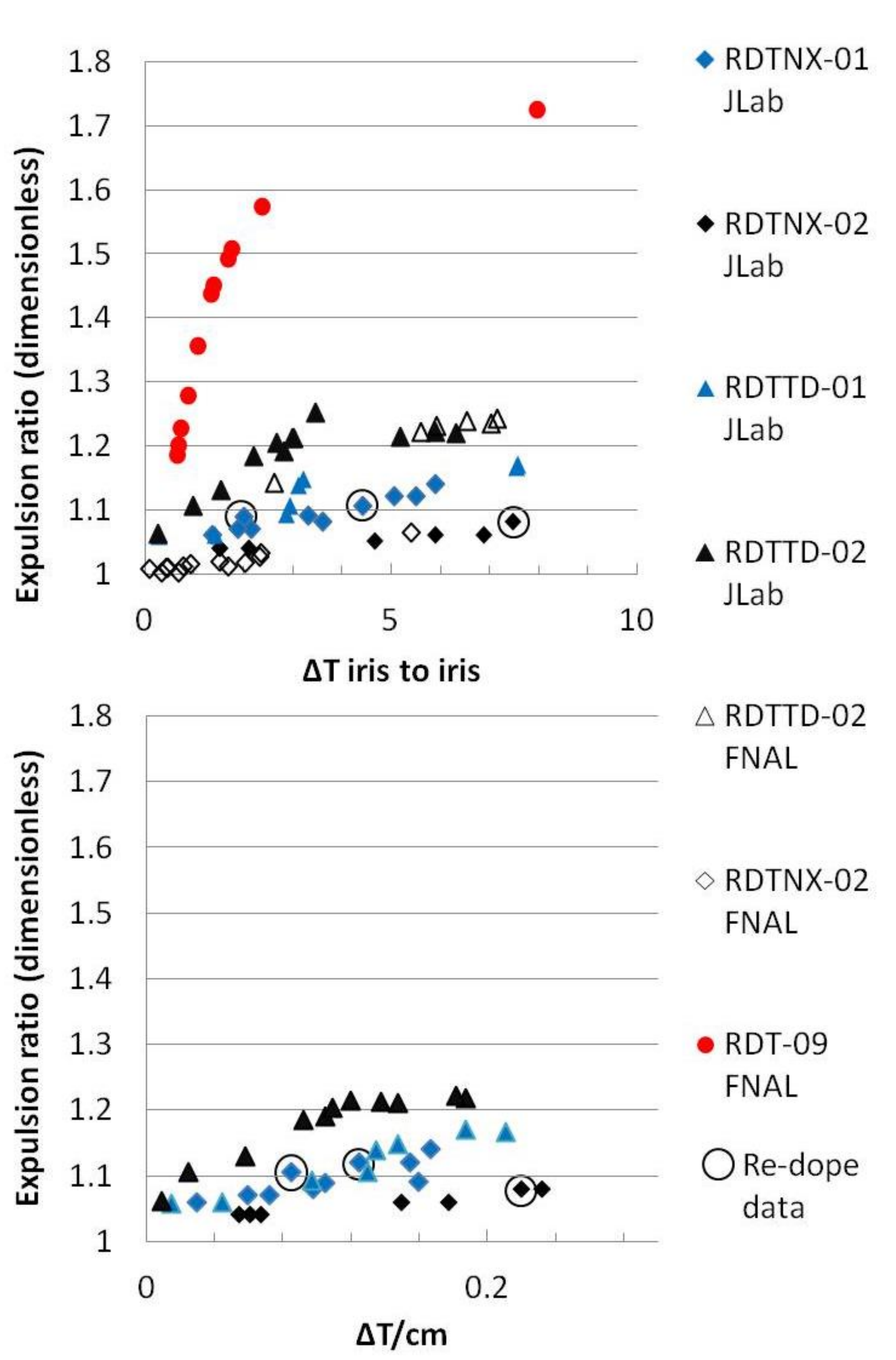
It has been shown that cooldown details through transition temperature can significantly affect the amount of trapped magnetic flux in SRF cavities, which can lead to performance degradation proportional to the magnitude of the ambient magnetic field [1]. It has also more recently been shown that depending on the exact material properties - even when the material used originated from the same batch from the same vendor - and subsequent heat treatment, the percent of flux trapped during a cool-down could vary widely for identical cool-down parameters [2] For LCLS-II, two material vendors have produced half of the niobium used for the cavity cells (Tokyo Denkai Co., Ltd. (TD) and Ningxia Orient Tantalum Industry Co., Ltd. (NX)). Both vendors delivered material within specifications set out by the project (according to ASTM B 393-05), which allows yet some variation of material characteristics such as grain size and defect density. In this contribution, we present RF and magnetic flux expulsion measurements of four single-cell cavities made out of two different niobium batches from each of the two LCLS-II material suppliers and draw conclusions on potential correlations of flux expulsion capability with material parameters. We present observations of limited flux expulsion in cavities made from the production material and treated with the baseline LCLS-II recipe.

[1] A. Romanenko, A. Grassellino, O. Melnychuk, and D. A. Sergatskov, Journal of Applied Physics 115, 184903 (2014).
[2] S. Posen, M. Checchin, A. C. Crawford, A. Grassellino, M. Martinello, O. S. Melnychuk, A. Romanenko, D. A. Sergatskov, and Y. Trenikhina, Journal of Applied Physics 119, 213903 (2016).

LCLS-II Material Properties used for Single-Cell Studies

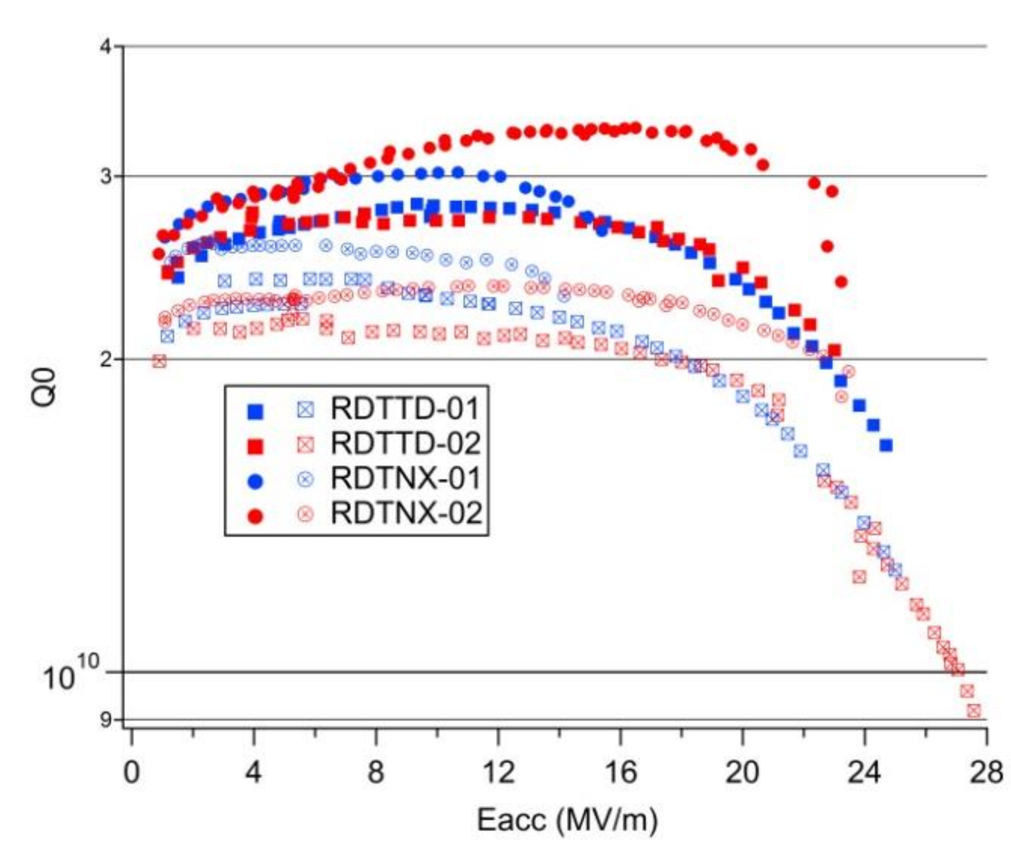
OTIC Ingot	RRR	HV Min	HV MAX	grain size ASTM	Cavity
ENT-132	380/412	44.6/35.7	56.6/39.3	5.5-6.0/5.0-5.5	RDTNX-01
ENT- 134	315/301	50.8/37.6	58.4/43.2	8.0/7.0-7.5	RDTNX-02
TD Ingot	**RRR**	**HV Min**	**HV MAX**	**grain size ASTM**	**Cavity**
1991	468	39.2	49.8	5	RDTTD-01
2022	365	36.4	42.5	7	RDTTD-02

Flux Expulsion Ratio Iris to Iris and ΔT/cm



Flux expulsion ratio in dependence of the temperature difference from cavity iris to iris (top) and the temperature gradient ΔT/cm (bottom). Data from a more ideal cavity RDT-9 made from non-LCLS-II production material are plotted in red circles for comparison. Circled data points are after additional 100 micron EP and additional doping (additional time in furnace at 800°C). The change in flux expulsion after additional time at 800°C is within error bars. Cryomodule cooldown specification for the project is about equal to the 5K iris-to-iris data in these plots.

RF Data and Residual Losses

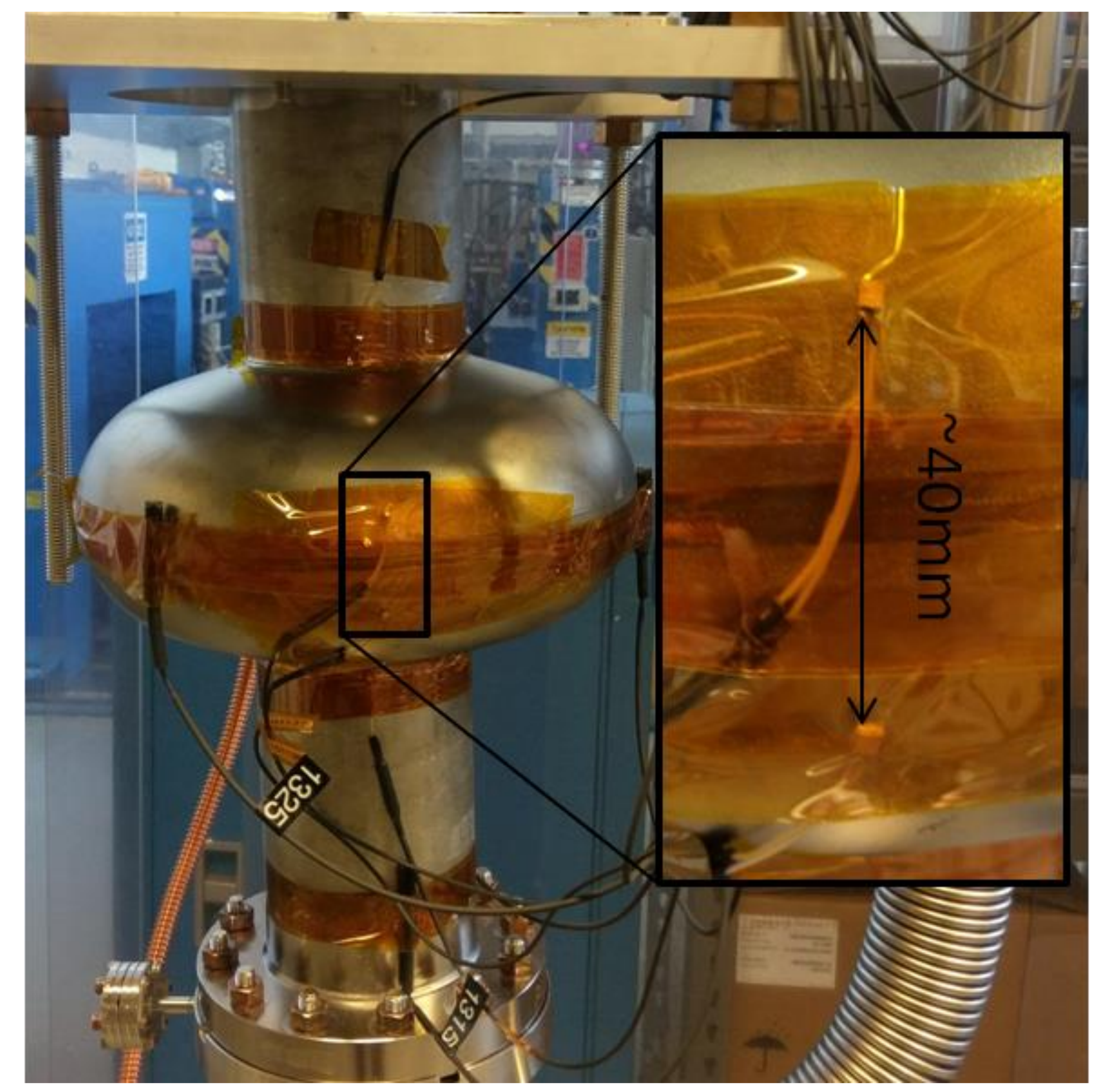


RF data for all 4 cavities in low field (~ 1mG, filled symbols) and high magnetic field (~ 5mG, crossed open symbols), respectively. RDTNX-01/02 data is after a second round of doping/EP. Extracted residual resistance changes at 16 MV/m are summarized below. The reason for extra residual losses of RDTTD cavities with 100 micron EP vs. RDTNX with 200 micron EP is under investigation.

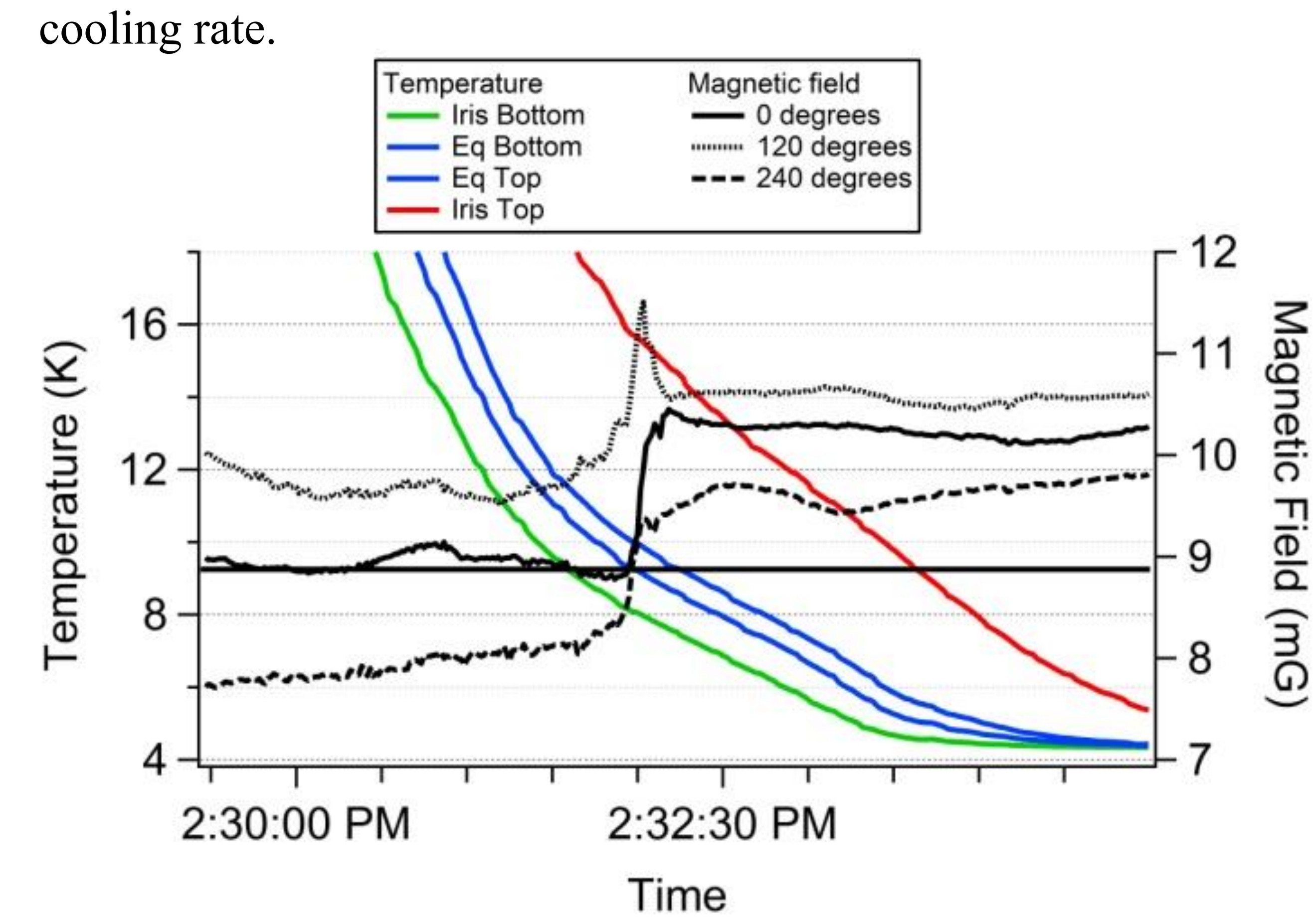
Cavity	R_S Δ @ 16 MV/m (nΩ)	Added Trapped flux scaled w/ ratio	nΩ/mG calculated with cooling rate flux ratio data
RDTTD-01	2.6	2.7	0.95
RDTTD-02	3.2	3.5	0.9
RDTNX-01	2.1#	3.6#	0.6#
RDTNX-02	3.6	3.8	0.93
# data @ 8MV/m			

Calculated RF losses and trapped flux loss ratio extracted from the expulsion ratio and RF data at 16MV/m.

Flux Expulsion Setup



Flux expulsion measurement setup: three fluxgate magnetometers on the equator (120 degrees apart), 2 Cernox sensors, one on each iris and then two 40 mm apart close to the equator for local cooling rate.



Example of flux expulsion ratio data from RDTTD-01 cooling from room temperature. Output: expulsion ratio of 1.15 for ΔT/cm = 0.18 or iris to iris temperature of 7.2 K.

Summary

- LCLS-II material exhibits a wide range of flux expulsion efficiencies depending on the material origin/supplier and batches.
- All material shows a flux trapped loss of ~1 nΩ/mG at 16 MV/m.
- All material shows flux trapping at levels which would not satisfy a cavity specification of Q0 = 2.7×10^{10} at 16 MV/m in a 5 mG field needed for the project.
- Additional time in the furnace at 800°C does not change flux expulsion as shown by the re-doping of the RDTNX cavities.
- Material studies are underway at 900°C rather than the baseline 800°C to improve the flux expulsion needed for the project.
- Additional EP and 900°C annealing followed by N-doping at 800°C is currently being tested on 9-cell production cavities for verification; the new recipe should allow all cavities to meet the specification of Q0 = 2.7×10^{10} at 16 MV/m in a 5 mG field needed for the project.

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