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NEW RESULTS OF DEVELOPMENT ON HIGH EFFICIENCY HIGH GRADIENT SUPERCONDUCTING RF CAVITIES*

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Abstract

We report on the latest results of development on high efficiency high gradient superconducting radio frequency (SRF) cavities. Several 1-cell cavities made of large-grain niobium (Nb) were built, processed and tested. Two of these cavities are of the Low Surface Field (LSF) shape. Series of tests were carried out following controlled thermal cycling. Experiments toward zero-field cooling were carried out. The best experimentally achieved results are E_{acc} = 41 MV/m at $Q_0 = 6.5\times10^{10}$ at 1.4 K by a 1-cell 1.3 GHz large-grain Nb TTF shape cavity and E_{acc} = 49 MV/m at $Q_0 = 1.5\times10^{10}$ at 1.8 K by a 1-cell 1.5 GHz large-grain Nb CEBAF upgrade low-loss shape cavity.

INTRODUCTION

Following the six-year (2006-2012) high-gradient SRF cavity R&D for ILC [1] and over a year of interruption due to SRF infrastructure upgrade at Jefferson Lab, we resumed the high gradient SRF R&D with an emphasis not only on gradient but also on efficiency. Initial results reported earlier in 2013 [2] were mixed due to the presence of strong field emission, consequential of irregularities in the SRF facilities before the full recovery in February 2014. After a 2-year hiatus, the high gradient SRF R&D at JLab was finally re-started for 1-cell testing. The new results since IPAC13 will be presented in this contribution.

Five L-band single-cell cavities, including two 1.3 GHz Low-Surface-Field (LSF) shape cavities, are fabricated using large-grain Nb. The choice of large-grain Nb is encouraged by the experimental demonstration of higher Q_0 at medium- and high- gradient regimes [3-5]. This gain in large-grain Nb cavity Q_0 is due to a lower residual surface resistance (roughly by a factor of 2) as compared to its fine-grain niobium counterpart [6]. The reason behind this difference may originate from different flux trapping behaviors [7]. Prior experimental results have established an average of residual resistance of 3-4 nΩ in 1.3-1.5 GHz large-grain Nb cavities.

Various surface processing and treatment techniques are adopted for comparison. The effect of cryogenic thermal cycling on the quality factor is studied. Higher values of Q_0 are realized at high as well as medium gradients. Several cavities achieved a $Q_0 \sim 3\times10^{10}$ at 15 MV/m, 2×10^{10} at 35 MV/m at 2K. A 1.5 GHz CEBAF upgrade low-loss shape cavity achieved a best result of E_{acc} = 49 MV/m at $Q_0 = 1.5\times10^{10}$ at 1.8 K. A 1-cell 1.3 GHz large-grain Nb TTF shape cavity achieved a best result of E_{acc} = 41 MV/m at $Q_0 = 6.5\times10^{10}$ at 1.4 K

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CAVITY DESIGN, MATERIAL, FABRICATION AND PROCESSING

All cavities are built by using the standard forming and electron beam welding techniques. Table 1 gives a summary on the design, material and fabrication facilities.

Table 1: Niobium Cavity Design, Material and Fabrication

Cavity	Freq	Shape	Material*	EBW facility
G2	1.3 GHz	TTF EC#	TD**	JLAB
PJ1-1	1.3 GHz	TTF CC##	Ningxia	JLAB
PJ1-2	1.5 GHz	LL###	Ningxia	Ningxia
LSF1-2	1.3 GHz	LSF	Ningxia	JLAB
LSF1-3	1.3 GHz	LSF	Ningxia	JLAB

EC: end cell; ##CC: center cell; ###LL: CEBAF upgrade low-loss shape. * All large-grain Nb disks are made from high RRR >300 ingot; ** TD: Tokyo Denkai.

Figure 1 shows the first completed LSF shape cavity (LSF1-2) along with cavity PJ1-1, parked in clean room, ready for final prepartion prior to vertical test.

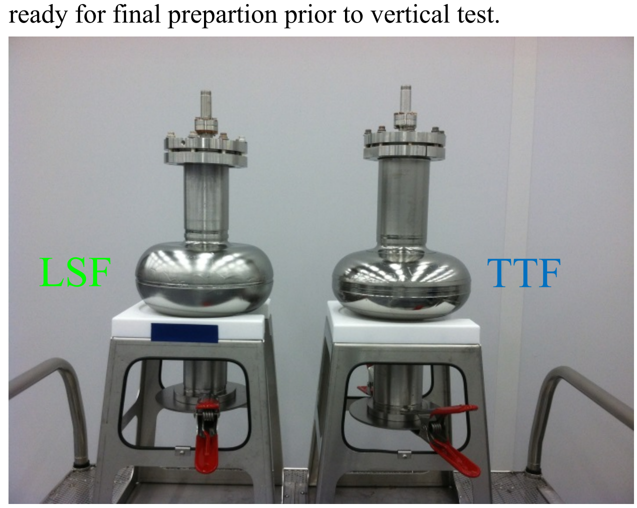

Figure 1: First 1-cell 1.3 GHz LSF shape cavity (L) made of large-grain Nb. A TTF shape 1-cell large-grain Nb cavity (R) is also shown for comparison.

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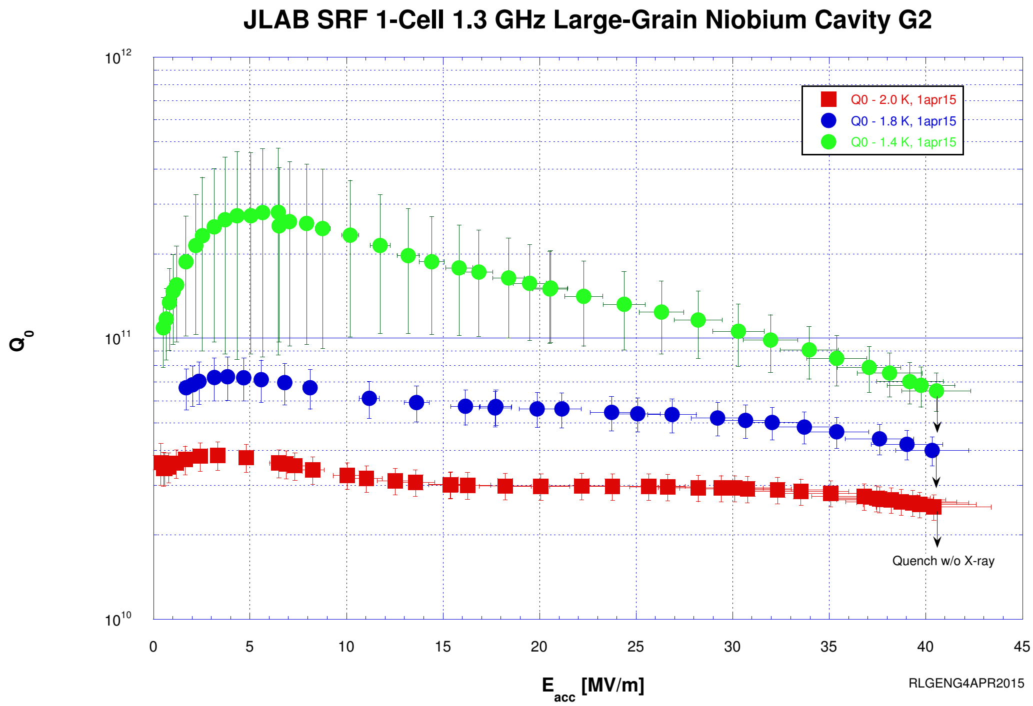

Figure 2: Performance of 1-cell 1.3 GHz large-grain Nb cavity G2. Gradient dependence of unloaded quality factor is measured at a bath temperature of 2.0 K, 1.8 K and 1.4 K. No detectable X-rays at the maximum gradient.

All cavities are heat treated at 800 °C for 2 hours following the bulk surface removal and are all high pressure water rinsed before final clean room assembly. Table 2 gives a summary of the bulk and final surface processing and achieved maximum B_{pk} and $Q_0(B_{pk}, 1.8K)$.

Table 2: Surface Processing, Maximum B_{pk}, $Q_0(B_{pk},1.8K)$

Cavity	Bulk Proc.	Final Proc.	B_{pk} [mT]	$Q_0(B_{pk},1.8K)$ [$\times10^{10}$]
G2	CBP	EP+LTB	174	4.0
PJ1-1	CBP	EP+LTB	147	3.1
PJ1-2	BCP	EP+LTB	206	1.5
LSF1-2	BCP	BCP+LTB	139	2.4
LSF1-3	BCP	BCP+LTB	136	2.7

CBP: mirror-finish centrifugal barrel polishing; BCP: Buffered chemical polishing at room temperature with HNO_3:HF:H_3PO_4 in volume ratio of 1:1:1; EP: electropolishing; LTB: low temperature baking at 120 °C.

TESTING RESULTS

Up to now, all the cavities listed in Table 2 have been tested in series. The final test result of cavity G2 is shown in Fig. 2. A maximum B_{pk} of 177 mT is reached with $Q_0 = 6.5\times10^{10}$ at 1.4 K. Fig. 3 shows the final result of PJ1-2. The maximum E_{acc} = 49 MV/m is reached with $Q_0 = 1.5\times10^{10}$ at 1.8 K. The corresponding B_{pk} and E_{pk} reaches 206 mT and 104 MV/m, respectively. No field emission induced X-ray was detected. Fig. 4 shows the final result of LSF1-3. The maximum E_{acc} = 37 MV/m is reached with $Q_0 > 2\times10^{10}$ at 1.8 K. A 30% gain in Q_0 is observed after a 20 K thermal cycling at 2K and 1.8K [8].

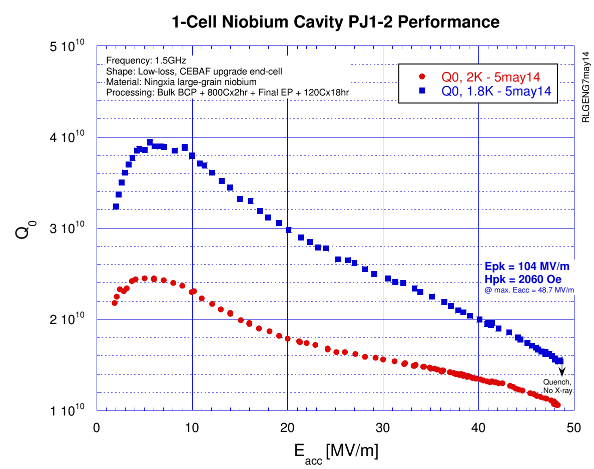

Figure 3: Performance of cavity PJ1-2 at 2K and 1.8K.

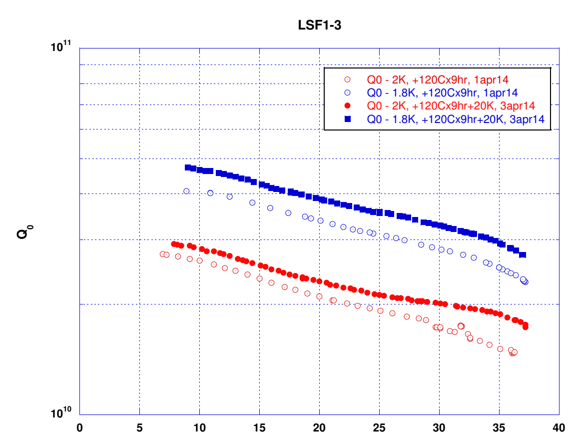

Figure 4: Performance of cavity LSF1-3 at 2K and 1.8K, before and after thermal cycling to 20K.

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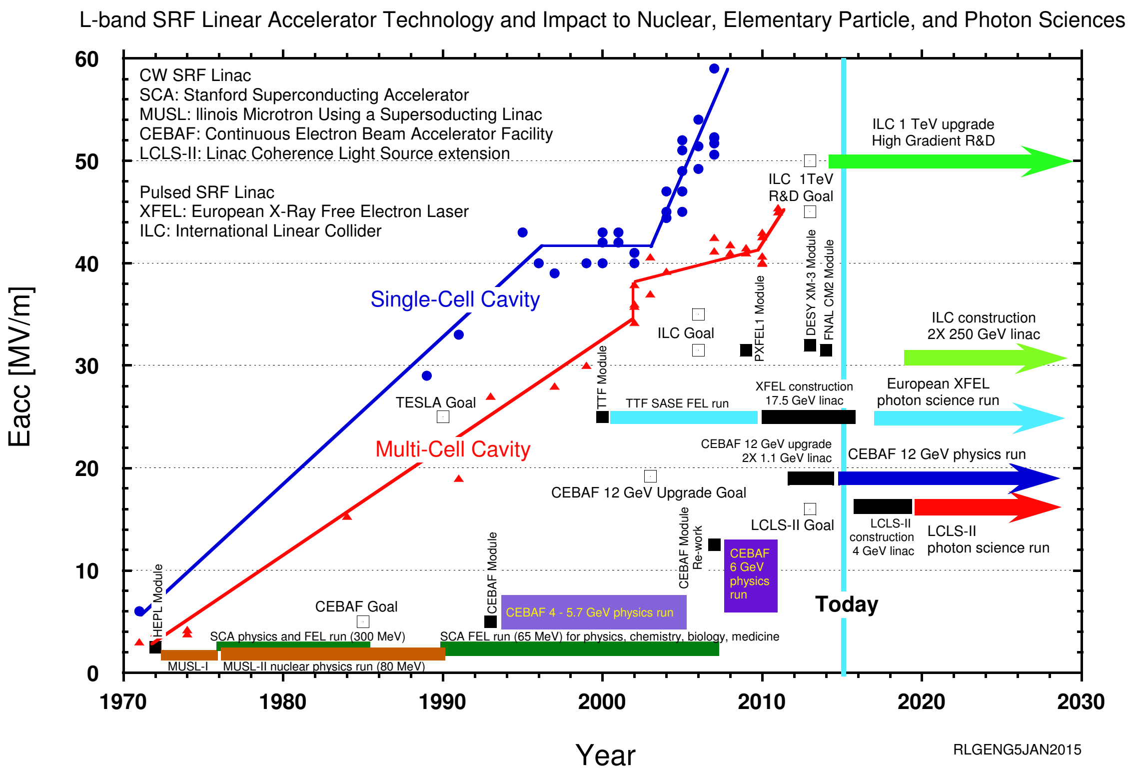

Figure 5: Evolution of acceleration gradient in L-band SRF cavities and its impact to SRF accelerators.

CONCLUSION AND OUTLOOK

Decades of R&D has resulted in steady progress in SRF gradient. As shown in Fig. 5, there is a track record that the full-scale practical multi-cell cavities follow the achieved performance in single-cell research cavities and the SRF accelerators ultimately benefit from the SRF R&D efforts. With the best 1-cell Nb cavities reaching a B_{pk} 200-210 mT, close to the theoretical limit, there is a final push to realize the ultimate gradient in mutli-cell cavities. New experimental results measured from L-band 1-cell large-grain Nb cavities in the past two years demonstrated significantly higher Q_0 values at a gradient > 35 MV/m. The best result we measured so far has established E_{acc} = 40 MV/m with Q_0=4×10^{10} at 1.8K. These results open new territories in the SRF performance map and demonstrate continued progress toward the theoretical limits. There are remaining fundamental (medium field Q-slope), technical (reliable control of field emission) and engineering (multi-cell demonstration in module and with beam) problems. Further research and development efforts are needed toward the application of high efficiency high gradient cavities in SRF accelerators.

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