HIGH-GRADIENT SRF R&D FOR ILC AT JEFFERSON LAB*

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Abstract

Jefferson Lab plays an active role in high-gradient SRF R&D in the frame work of the internationally coordinated International Linea Collider (ILC) S0 program. The S0 aim is to push the yield at 35 MV/m in 9-cell cavities. So far, twelve cavities have been electropolishing (EP) processed and RF tested by using the state-of-the-art recipes at JLab, in close collaboration with FNAL and KEK. Seven of them reached a best gradient of over 31.5 MV/m. Understanding gradient limiting mechanisms in real 9-cell cavities is an important component of our studies. Thermometry and high-resolution optical inspection are used to locate and understand the source of gradient limits. Experimenting with selective cavities is still a necessary method for process optimization. One example is the first demonstration of 35 MV/m without detectable Bremsstrahlung X-ray after a light EP is applied to a previously heavy chemical etched 7-cell cavity. Some new understanding has been gained with regard to quench behaviors, field emission behaviors as well as optimized processing. Progress has been made as a result, exemplified by the recent achievement of ≥ 35 MV/m in two cavities, each after the first light EP. Several exploratory studies are under way at JLab, aiming to covert the new understandings into further improved cavity gradient results.

INTRODUCTION

A summary of our earlier high-gradient cavity R&D work for ILC was reported at SRF2007 and can be found in Ref. [1]. Seven 9-cell cavities (A6, A7, A8, AES1, AES2, AES3 and AES4) were reported therein. The present report focuses on the new results obtained after the 2007 SRF Workshop. These include continued studies of four old (AES2, AES3, AES4 and A8) cavities and new studies of ***five new cavities*** (I5, A11, A12, A15 and J2). Till the present time, twelve 9-cell cavities have been EP processed and tested. In addition, a previously chemically etched 7-cell cavity was electropolished for 30 micron surface removal and reached an excellent result. Over 100 hours of active EP time has been accumulated.

Improvements in many areas have been made toward optimized processing. Initial acid mixing is made using a volume ratio of 1:10 (HF(49%):H_2SO_4(96%)). Nominal voltage across the cavity and cathode is 14-15 V. Acid supplying holes in the cathode face upward. The optimal EP is done in the continuous current oscillation mode [2][3]. More active temperature control is accomplished by steering the cooling water in the heat exchanging loop. The minimum purging N_2 gas flow reduces HF loss. Sealing openings around the acid sump prevents water (moisture) addition into acid and also reduces HF loss. High pressure water rinsing (HPR) after bulk EP and before 600°C furnace heat treatment improves cleaning and avoids burning chemical residuals into surface.

A major enhancement of our cavity gradient studies is added instrumentation of T-mapping and high-resolution optical inspection (Fig. 1). We will give some examples of understanding cavity quench and field emission behaviors by using these new capabilities.

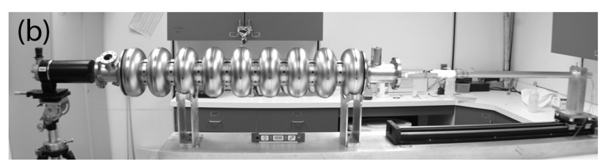

Figure 1: 9-cell cavity T-mapping (a) and high-resolution optical inspection (b) instruments used at Jefferson Lab.

9-CELL CAVITY RESULTS

Four (AES2, AES3, AES4 and A8) of the nine studied cavities were previously reported in Ref. [1]. Their further study results are reported herein. AES2 reached a best gradient of 32.8 MV/m. A8 reached a best gradient of 31.7 MV/m. AES3 was previously found [1] quench limited at 17-19 MV/m with the rough location of the quench origin determined. Finally, with 16 thermometers attached to the suspected region, the quench location was pinpointed by using FNAL's fast thermometry system. AES4 remained field emission limited at the gradient level of 27-29 MV/m despite further re-processing efforts.

Five of the nine cavities reported here are *new cavities*: three (A11, A12 and A15) are from the new batch of ACCEL procurement; one (I5) from KEK; one (J2) from the two new 9-cell cavities fabricated at Jefferson Lab.

A complete summary of all RF tests and associated surface processing histories is given in Table 1.

The best $Q(E_{acc})$ of cavities manufactured by "qualified" vendor (A8, A11, A12 & A15) and new

* Work supported by DOE and US-Japan Collaboration. Authored by Jefferson Science Associates, LLC under U.S. DOE Contract No. DE-AC05-06OR23177.
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vendors (AES2, AES3, AES4, I5 & J2) are given in Fig. 2(a) & (b), respectively.

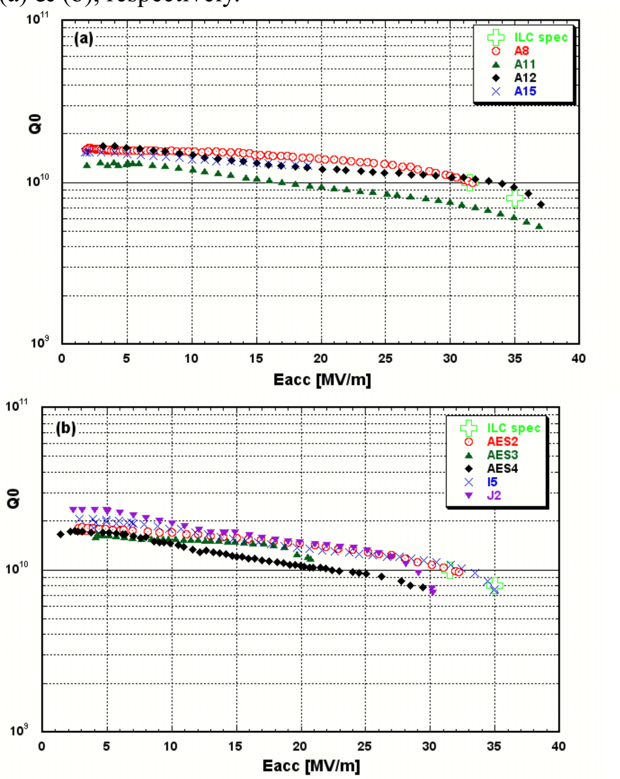

Figure 2: Best Q(E_{acc}) of 9-cell ILC cavities EP processed and tested at Jefferson Lab. Cavities fabricated by "qualified" vendors (a) & new vendors (b). Note: low Q value of A11 is likely due to frozen flux effect and A11 will be re-tested; High field Q-slope in J2 is likely caused by non-optimal bulk EP and another light EP will follow.

UNDERSTANDING QUENCH BEHAVIORS

We have two quench limited cavities further studied for understanding location and nature of responsible defects.

The first is AES3. Following previous studies [1], by using FNAL's fast thermometry system, the exact location of quench source in AES3 was finally determined to be near but outside of the equator EBW of the cell #4 (note: cell number is counted from side of input coupler port). The AES3 quench behavior is very close to that of AES1 (quench limited at gradient < 20 MV/m in fixed cell pairs despite repeated EP). In case of AES1, the location of quench source was determined and defects (pit/bump of 400-600 μm in diameter) were observed in the heat-affected zone of the equator weld of cell #3 [4].

A15 is the other successful example of finding responsible defects in a real 9-cell cavity. By using the combined technique and instrumentation of pass-band measurements, cavity cell thermometry, and high-resolution optical inspection of cavity RF surface, a "hot spot" (correlated to quench at 17-19 MV/m) was captured and a pit (with estimated depth of 50 μm) of 200-300 μm in diameter was discovered within 1cm distance from the hot spot (Fig. 3). The defect is located in the heat affected zone of the equator EBW of cell #3 of A15.

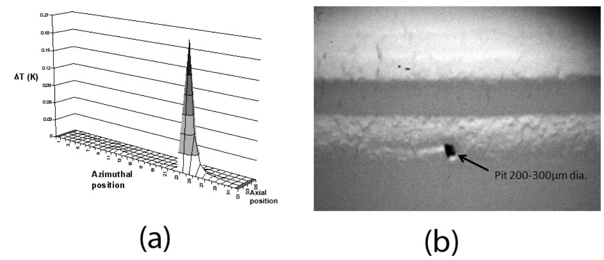

Figure 3: (a) hot spot captured by T-mapping near equator EBW of cell #3 of A15; (b) pit discovered on RF surface within 1cm distance from hot spot.

UNDERSTANDING FE BEHAVIOR

FE remains an issue deserving attention, despite progress made recently. Here we report a FE behavior that can be generally characterized as FE turn on.

The first kind of FE turn on seems to be correlated to the presence of defects (sub-mm in diameter). Substantial Q-decline is resulted. It is observable in AES4 and I5 despite repeated EP processing. Fig. 4 gives some example defects discovered in these two cavities. These defects are located in the high electric field region of end cells, coinciding with the high FE cell pairs determined by pass-band measurements.

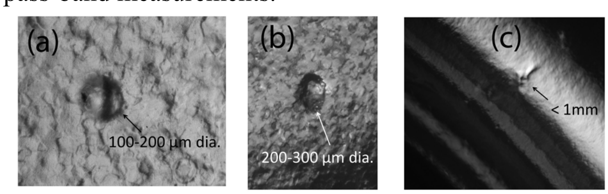

Figure 4: Defects observed in the high electric field region of high FE cells. (a) Circular defect in cell #9 of AES4 at radial location of stiffening ring. (b) Circular defect in cell #8 of AES4 near iris weld. (c) Linear defect near iris of end cell of I5.

The second kind of FE turn on is induced by low temperature bake. Only subtle Q decline is resulted. It was observed in A11 & A12. They were tested before low temperature bake with no detectable X-ray up to 28 & 30 MV/m, respectively. After low temperature bake, sudden FE turn on was observed during the first power rise at 25 & 23 MV/m, respectively. More details on this kind of FE behavior will be published in the future.

Re-processing by ultrasonic cleaning with detergent followed by HPR has been found effective in reducing FE in previously RF tested and heavily FE loaded cavities. A remarkably successful example is the 5^{th} RF test of I5 after re-processing with 2% micro-90 ultrasonic cleaning and HPR [6]. There was virtually no detectable Bremsstrahlung X-ray during the test up to 35 MV/m. The effectiveness of this re-processing technique has been further confirmed in two other cavities.

A related result worth mentioning is that a previously heavy BCP (buffered chemical polishing) etched 1.5 GHz 7-cell cavity (HG006) reaches a gradient of 35.3 MV/ without detectable Bremsstrahlung X-ray (Fig. 5). No low temperature induced FE turn on is observed, a clear contrast to FE behaviors of A11 & A12.

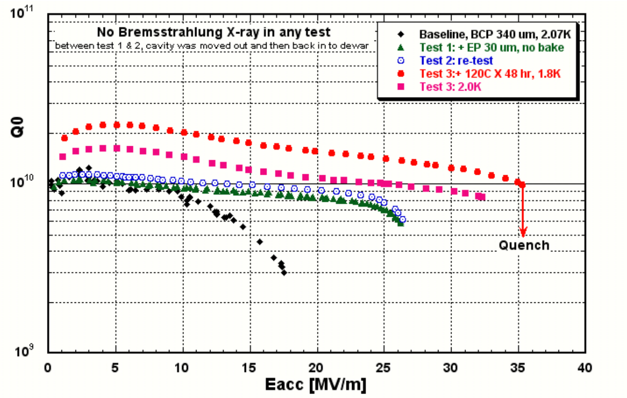

Figure 5: An example of initially BCP etched multi-cell cavity achieving 35.3 MV/m after a 30 µm EP. No detectable Bremsstrahlung X-ray up to 35.3 MV/m.

SUMMARY

Progress has been made in understanding quench and FE behaviors in real 9-cell cavities. Some sub-mm sized defects in the heat affected zone of a niobium EBW are responsible to some observed quench and maybe even some observed FE turn on. Further studies are needed to understand the origin and evolution of these defects. An exploratory study is under way at JLab, aiming to remove these kinds of defect by local niobium re-melting technique. A baking induced FE turn on phenomenon was observed. Some positive sign has been demonstrated by applying HPR after bake, as shown by a preliminary experiment. Re-processing with detergent ultrasonic cleaning and HPR has been found effective in reducing/eliminating FE in previously RF tested cavities up to 35-39 MV/m. An example of a multi-cell cavity reaching 35 MV/m without detectable Bremsstrahlung X-ray has been demonstrated by applying a light EP to a previously heavy BCP etched cavity.

Twelve 9-cell cavities have been EP processed and tested at JLab. Eight of them exceeded a best gradient of 30 MV/m. Two of them exceeded 35 MV/m after the first light EP. We believe further improvement is possible by streamlined process of Integrated Cavity Processing (ICP) that is being conceived at JLab. Design studies and initial prototyping with a 1-cell cavity set-up is under way.

ACKNOLEDGEMENTS

We thank the following colleagues for their important contributions to the presented work: Damon Bice of FNAL and Byron Golden, Pete Kushnick, Danny Forehand and Michael Morrone of Jefferson Lab.

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Table 1: Summary of Cavity Processing and Testing. (EP = electropolishing; ER = ethanol rinsing; USC = ultrasonic cleaning with detergent solution; HPR = high pressure water rinsing; LTB = low temperature bake; FE = field emission; FEIQ = FE induced quench; FETO = FE turn on.)

Cavity	Test	Processing	Max. E_{acc} [MV/m]	Limit
AES2	3	+EP 20µm	26.0	Quench
AES2	4	+EP 20µm	32.8	Quench
AES3	5[#]	+EP 20µm	21.0	Quench
AES4	5	+EP 20µm	17.0	RF cable
AES4	6	+HPR	23.0	Quench
AES4	7	+USC,HPR	27.0	FE
AES4	8[##]	+USC,ER,HPR	29.4	FEIQ
I5	1	+USC,HPR	30.0	(note §)
I5	2	(re-test)	21.0	FETO
I5	3	(re-test)	19.0	FETO
I5	4	+EP 30µm	36.0	FETO
I5	5	+USC,HPR	35.0	Quench
I5	6	+EP 40µm	28.0	FETO
I5	7	+EP 20µm, ER	29.0	FE
A8	4	+EP 20µm	31.7	Quench
A11	1[†]	EP 170µm[¥]	28.0	Q-drop
A11	2	+LTB	37.0	Low Q
A11	3[††]	(re-test)	36.0	Low Q
A12	1[†]	EP 170µm[¥]	30.0	FE
A12	2	+USC,HPR	30.5	Q-drop
A12	3	+LTB	36.6	FE
A12	4	+HPR	37.0	Q-drop
A15	1	EP 170µm[¥]	17.0	Quench
A15	2[♣]	(re-test)	19.0	Quench
J2	1	EP 170µm[¥¥]	30.0	Q-drop

[#]Testing with FNAL’s fast thermometry, found quench source location in cell #4.
[##] Testing with JLab’s “2 of 9” thermometry, aiming for locating field emitters in end cells.
[§]Testing was limited by liquid helium and loose antenna.
[†]RF testing before low temperature bake.
[††]Re-testing after parking cavity at 70 - 140K for 16 hours. Test confirmed cavity had no Q-disease.
[¥]First RF test of original as-built cavity is after nominal total surface removal of 170 µm (150 µm from bulk EP and 20 µm from light EP). Cavity was NOT low temperature baked before first RF test.
[♣]Testing with JLab’s “2 of 9” thermometry, found quench source location in cell#3.
[¥¥]HPR applied after low temperature bake and before 1[st] RF test.