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# HIGH-GRADIENT SRF CAVITY R&D AT CORNELL UNIVERSITY*

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*Abstract*

Achieving high accelerating field is a critical R&D topic for superconducting RF cavities for future accelerators including the International Linear collider (ILC). The ILC requires an average accelerating field of 35MV/m with a $Q_0$ of at least $8.9\times10^9$ at 2K. In this paper, we report the latest results from high-gradient research at Cornell, which focusses on 75°C vacuum baking to improve maximum (quench) fields. We demonstrate that such low temperature bakes can significantly improve quench fields in certain cases. We further report on high-pulsed power results of these cavities before and after baking.

## INTRODUCTION

High-gradient SRF cavities R&D is critical for future superconducting accelerators. The proposed International Linear Collider (ILC) for future High-Energy Physics research ought to generate a beam energy of up to 250 GeV [1]. Hence the SRF cavities, the key component of this accelerator, are required to provide an operating accelerating gradient of 35MV/m with the quality factor above $8.9\times10^9$ at 2K.

The 75°C baking effect [2] had been firstly discovered after a furnace malfunction during a standard 120°C baking; the cavity after the non-standard bake reached nearly 50MV/m. Hence, it is warranted to carry out dedicated low-temperature baking studies aiming at benefiting SRF cavity performance for future accelerator projects.

## CAVITY PREPERATION

We used two 1.3 GHz ILC-type single-cell SRF cavities (LTE1-14 and LTE1-15) and a 2.6 GHz ILC-shape SRF cavity (STE1-1) for this work. As the baseline treatment of the 1.3GHz cavities, the cavities were treated by the ILC baseline recipe [3], i.e. 100 µm surface removal by electro polishing (EP), and 900°C baking for 3 hours, and then 120°C baking for 48 hours. After the baseline treatment, both cavities have been vertically tested on the Cornell waveguide insert allowing regular CW and high-power pulse measurement in same cryogenic cycle. After that, the cavity LET1-14 was baked at 800°C for 3 hours then baked at 120°C under ~40mTorr $N_2$ for 48 hours. LET1-14 has been tested after the infusion. Finally, the cavity was 75°C baked for 6 hours on the insert and tested again.

LTE1-15 received a 1st 75°C baking for 6 hours on the insert after the baseline test; then the cavity was tested again. After that we HF rinsing of the cavity was preformed, followed by another test. Lastly, a 2nd 75°C baking was carried out for the cavity on the insert and followed by a final vertical test.

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STE1-1 was baked in a 40mTorr $N_2$ atmosphere at 160°C for 48 hours before the cavity was vertically performance tested. After the test, the cavity was HF rinsed to regrow the oxide layer on the surface and then it was loaded into a furnace for a 6 hours 75°C vacuum bake.

The set-up for the 75°C baking on the wave-guide insert is shown in Fig. 1. The reason for baking on the insert is to minimize chances of contamination from cavity disassembly. During the baking, a heat gun blows hot air to keep cavity at the temperature of 75 ± 3°C.

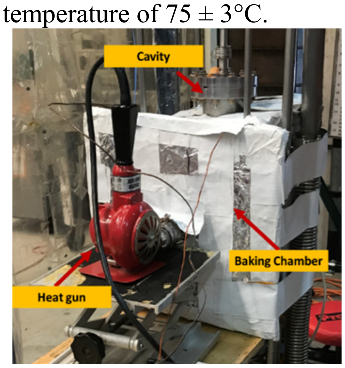


Figure 1: Set-up of 75ºC baking on the waveguide insert.

## TEST RESULTS AND ANALYSIS

The $Q_0$ versus $E_{acc}$ results from cavity LTE1-14 are summarized in Fig. 2. The baseline test showed that the cavity quenched around 23MV/m with an average 2K $Q_0$ of $\sim1.4\times10^{10}$. After the 120°C infusion, the quench field was increased to 26 MV/m with average $Q_0 \sim 2\times10^{10}$ in CW measurement. The cavity achieved 40MV/m in high-power pulse (HPP) tests in which 300kW, 250 µs high-power pulses were applied to the cavity, as is shown in Fig. 3. The 75°C baking decreased the cavity $Q_0$ to $1.2\times10^{10}$, but the maximum CW field was improved to 30 MV/m. In the three tests, there no medium-field Q-slope was observed. The maximum gradients in CW and HPP operation are summarized in Table 1.

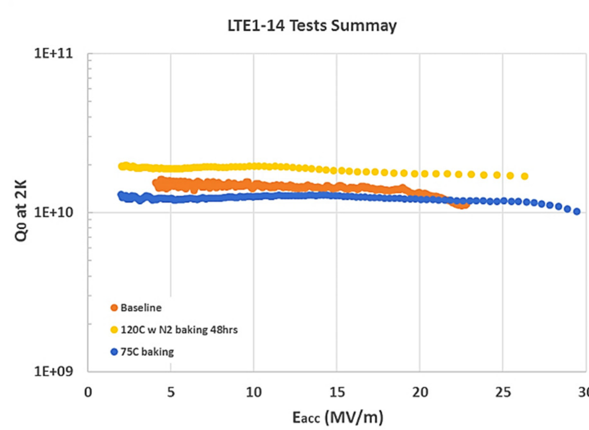


Figure 2: LTE1-14 $Q_0$ vs. $E_{acc}$ curves at 2K.

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Figure 4 shows the $Q_0$ versus $E_{acc}$ measurements for cavity LTE1-15. The baseline test showed a quench around 24 MV/m. After the 1st 75°C baking, the cavity gradient increased to 35 MV/m, but the cavity showed heavy field emission (FE) and low high-field $Q_0$. The cavity was disassembled for HF rinsing and re-HPR to reduce residual resistance and eliminate the FE. Afterwards, $Q_0$ had improved, but the quench field decreased to 26 MV/m. Likely, the HF rinsing removed the 75°C baking effect. We then carried out a 2nd 75°C baking of the cavity, but the performance did not change in the following test. The quench fields of LTE1-15 in CW and HPP measurements are summarized in Table 2.

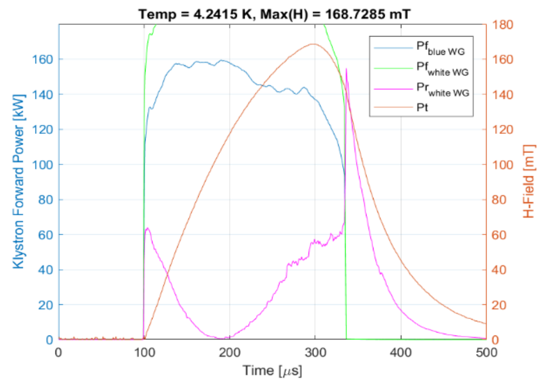



Figure 3: HPP test results after 120°C infusion showing the maximum B-field achieved was 169 mT, i.e. $E_{acc}$ ~ 40 MV/m.

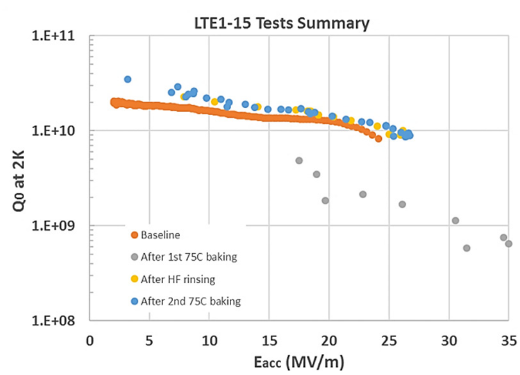



Figure 4: LTE1-15 $Q_0$ vs. $E_{acc}$ curves.

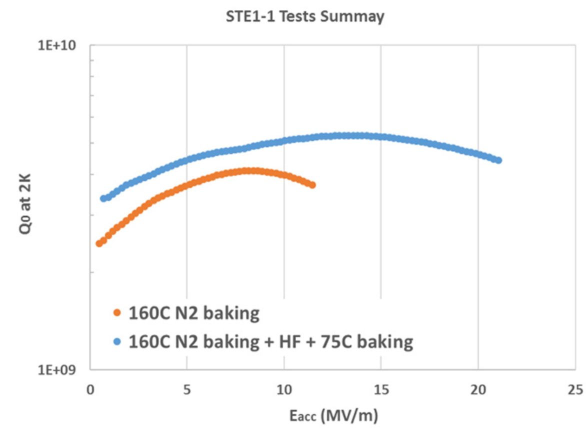



Figure 5: LTE1-15 $Q_0$ vs. $E_{acc}$ curves.

The comparison of the Q vs. $E_{acc}$ curves of STE1-1 before and after 75°C baking is showed in Fig. 5. In this case, we performed a HF rinsing to reduce $R_0$. The maximum accelerating field was dramatically improved after the baking.

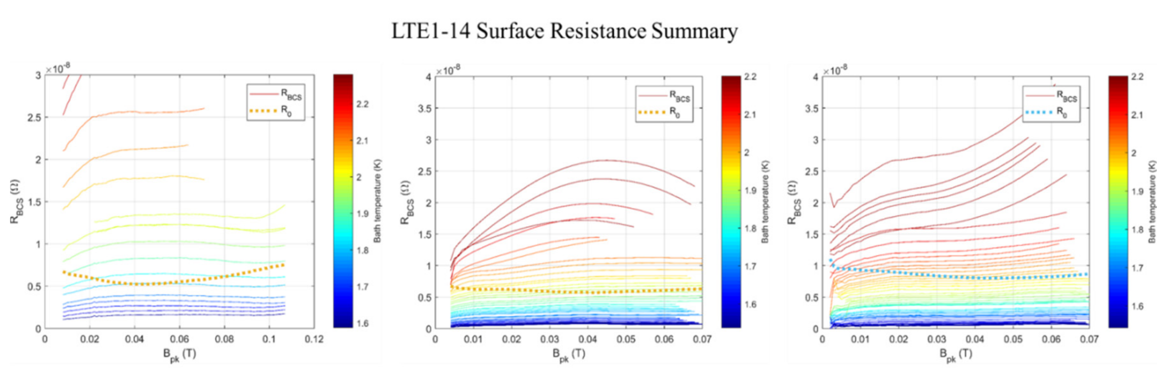
The LTE1-14 and LTE1-15 surface resistance results are summarized in Fig. 6 and Fig. 7 respectively. Frequency versus temperature data was taken during cavity warm-up. The mean-free-path of each treatment was extract from these and are listed in Table 3 and Table 4 for LTE1-14 and LTE1-15 respectively.

Table 1: LTE1-14 Quench Field Summary

| **Treatment** | **CW** (MV/m) | **HPP** (MV/m) |
|---|---|---|
| Baseline | 23 | NA |
| 120°C baking with N2 | 26 | 40.2 |
| 75°C baking | 30 | NA |

Table 2: LTE1-15 Quench Field Summary

| **Treatment** | **CW** (MV/m) | **HPP** (MV/m) |
|---|---|---|
| Baseline | 24 | 34.3 |
| 1st 75°C baking | 36 | NA |
| HF rinsing | 26 | NA |
| 2nd 75°C baking | 26 | NA |




(a) Baseline test (b)120°C baking 48 hours with N2 (c)75°C baking 6 hours

Figure 6: LTE1-14 surface resistance summary.

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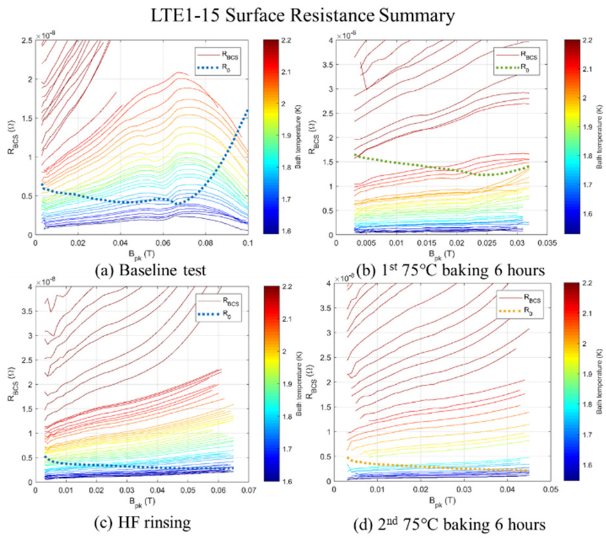


Figure 7: LTE1-15 surface resistance summary.

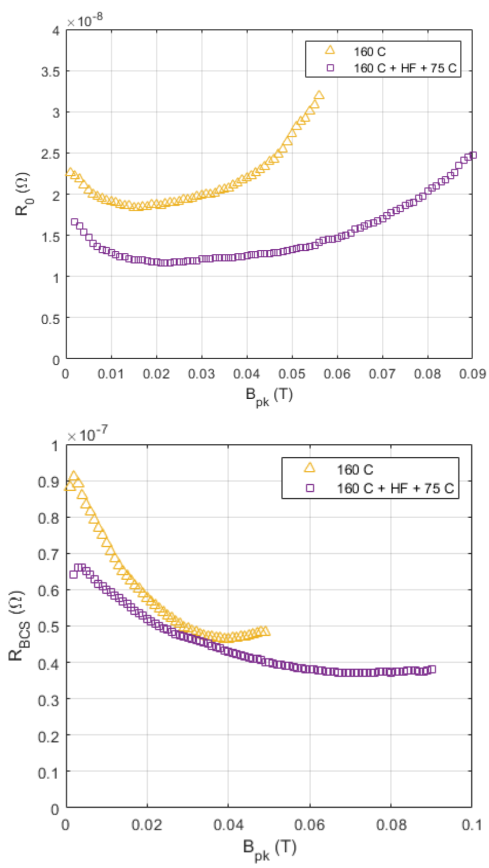


Figure 8: STE1-1 surface resistance summary. The top-plot summarizes $R_0$ and bottom-plot is the comparison of $R_{BCS}$.

The comparison of the surface resistance, shown in Fig. 8, shows that the residual surface resistance had been dramatically reduced by the HF rinsing and 75°C baking. The minimum $R_0$ after the HF rinsing is closed to 10 nΩ, almost 50% less than the value before the treatment. The $R_{BCS}$ before and after the treatment is very close in the medium-field region.

Table 3: LTE1-14 Mean-free-path Summary

| Treatment | Mean free path (nm) |
|---|---|
| Baseline | ~260 |
| 120°C baking with $N_2$ | 2.4 |
| 75°C baking | 47 |

Table 4: LTE1-15 Mean-free-path Summary

| Treatment | Mean free path (nm) |
|---|---|
| Baseline | ~260 |
| 1st 75°C baking | 83 |
| HF rinsing | 71 |
| 2nd 75°C baking | 62 |

## CONCLUSION

A series of surface preparation recipes has been studied via two 1.3GHz ILC-type SRF cavities (LTE1-14 and LTE1-15) and one 2.6 GHz ILC-shape SRF cavity (STE1-1). The 1.3 GHz cavity results after the infusion showed that the residual resistance was at the same level as for the baseline test, but the BCS resistance had been reduced to below 10 nΩ. Hence the $Q_0$ had been improved to ~$2\times10^{10}$. We applied 75°C baking after 120°C baking. The 75°C baking increased residual resistance in both tests, but it did not dramatically change the BCS resistance. In the 2.6 GHz cavity case, the both residual and BCS resistances were reduced after the HF rinsing plus 75°C baking.

The cavities achieved much higher $E_{acc}$ in the HPP tests in which ~300kW 250µs high-power pulse was applied to the cavities. We observed that the maximum field of the cavities had improved after 75°C baking in both 1.3 GHz and 2.6 GHz cavity cases. Frequency versus temperature fitting shows that the mean-free-path (MFP) became extreme short ~2.4nm after 120°C infusion; but the MFP level was 47-83 nm after 75°C baking

## REFERENCES

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[3] H. Hayano, "Review of SRF cavities for ILC, XFEL, and ERL applications", in *Proceeding of IPAC10*, Kyoto Japan, 2010, paper THXRA02.