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Understanding Surface Contamination Effects in Mid-T Baked Cavities

VIJAY CHOUHAN

TTC WG high-Q/high-G remote meeting

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Contents

Introduction & Motivation

- Mid-T baking of Nb cavities is usually carried out at 300–350 °C to enhance their Q-values.
- Mid-T baking in this temperature range can lead to the formation of surface contaminants, primarily niobium carbides. Contamination level depends on furnace cleanliness/residual gases, which vary between furnaces and across facilities.
- **The motivation to perform this study is to:**
  - **Determine the effect of the surface contaminants formed during mid-T baking on cavity performance**
  - **Develop a method to improve cavity performance if the performance is adversely affected by these contaminants**

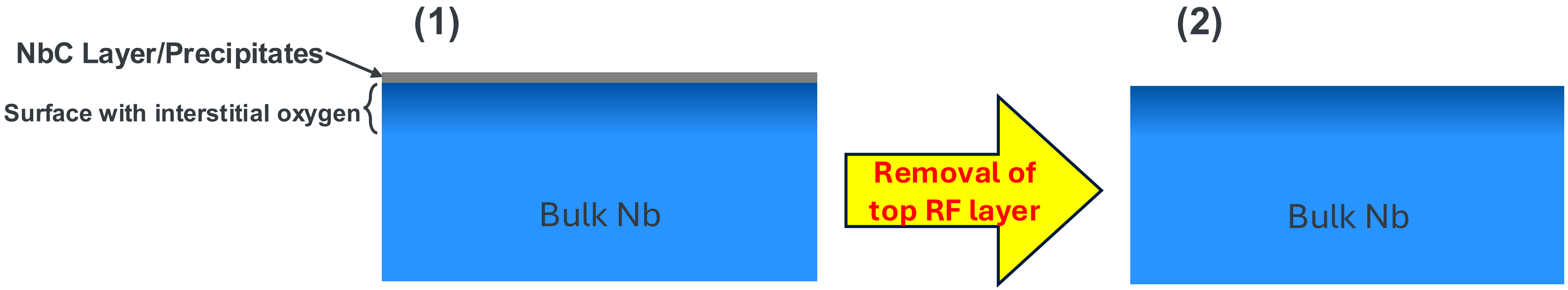
Strategy to determine contaminants effect

To understand the effect of carbides, we must compare performance of the same cavity in two scenarios:

(1) with carbides/contaminants present on the cavity surface

(2) without carbides/contaminants on the cavity surface

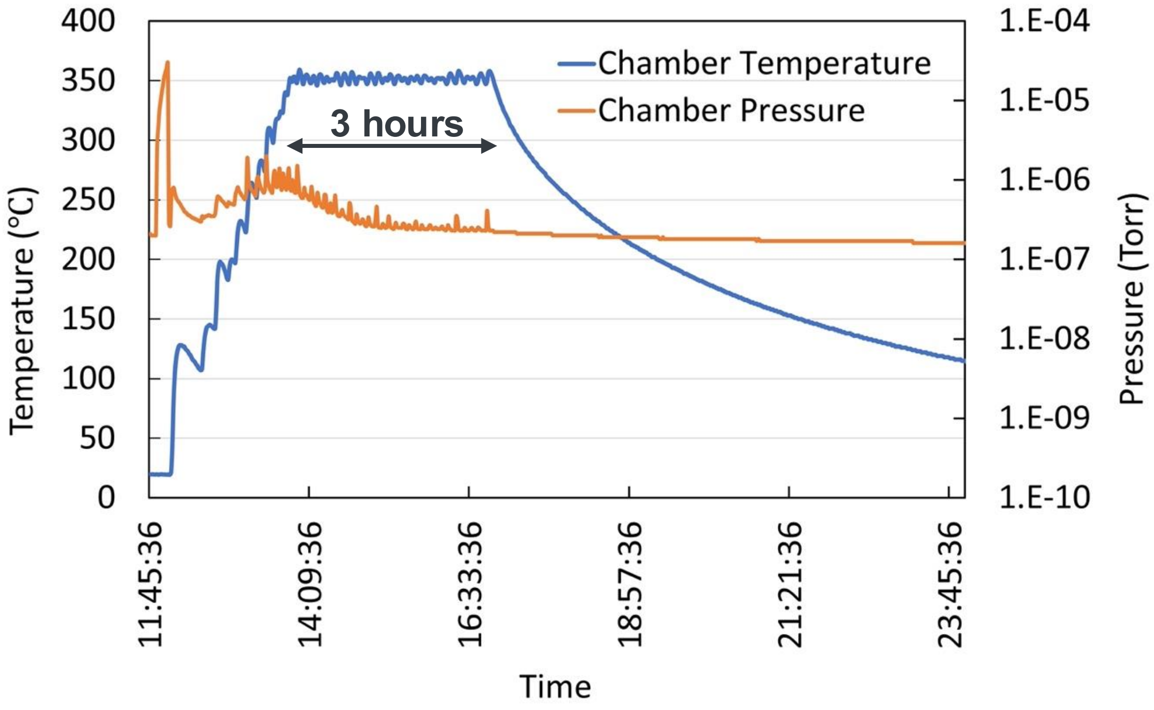
while keeping the oxygen concentration in the RF layer the same in both cases.



Mid-T baking of cavities and samples

- High-gradient cavities were selected for the mid-T baking study.
- Cavities:
  - **1.3 GHz single-cell**
  - **650 MHz single-cell**

Cavities ready to enter furnace



- Both cavities were placed in the furnace and mid-T baked together at **350 °C for 3 hours**.
- Witness samples set in an Nb box were also installed in the furnace.

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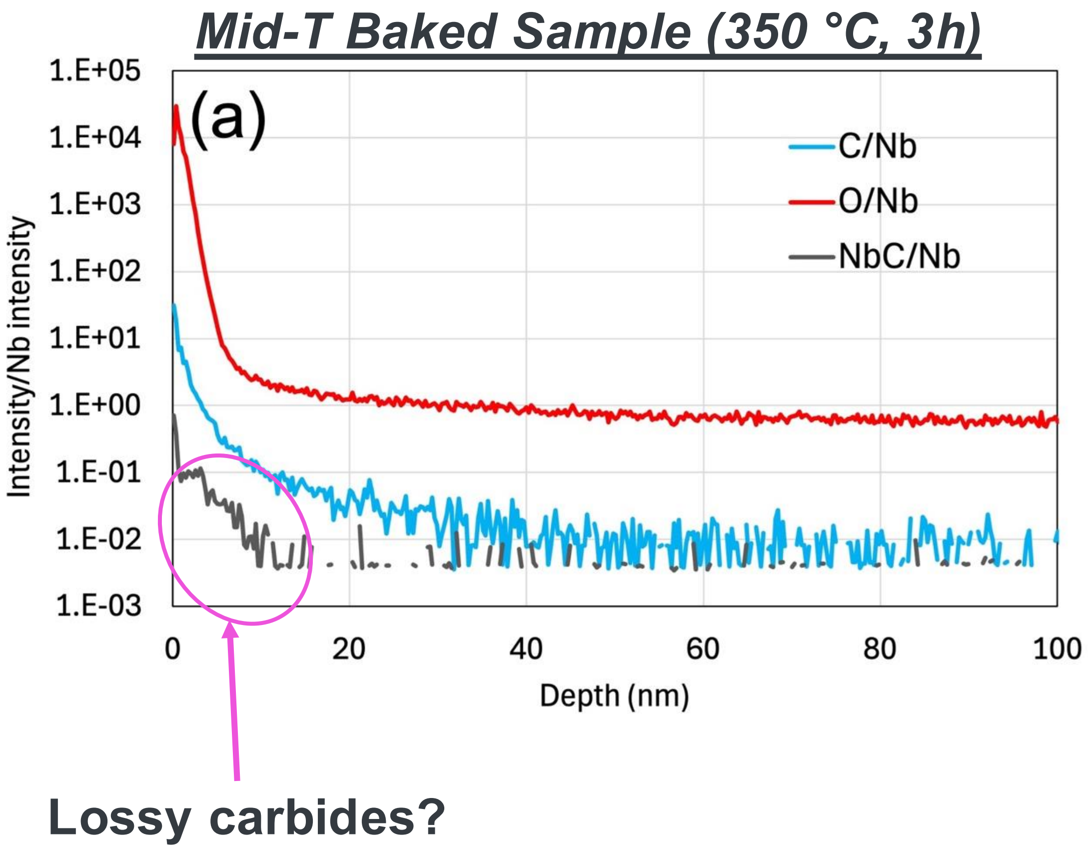
Sample results

SIMS analysis of mid-T baked sample

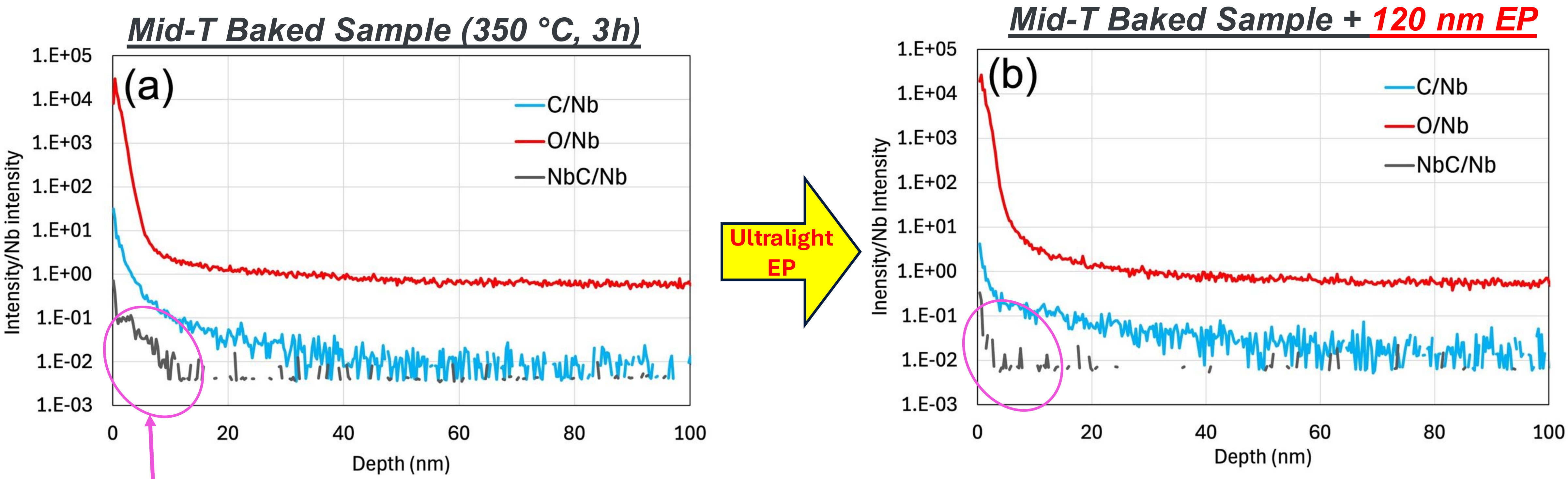
- Mid-T baked samples were analyzed with secondary ion mass spectrometry (SIMS) to evaluate surface contaminants.



- The SIMS data showed an elevated NbC intensity within the top tens of nanometers of the surface.

SIMS analysis after ultralight EP

- The spectra were compared with another mid-T baked sample that received **ultralight EP for 120 nm** removal.



Lossy carbides?

- NbC intensity was close to the background for the sample subjected to 120 nm removal after mid-T baking.
- Such a difference was observed between mid-T baked and EP-only samples.

02

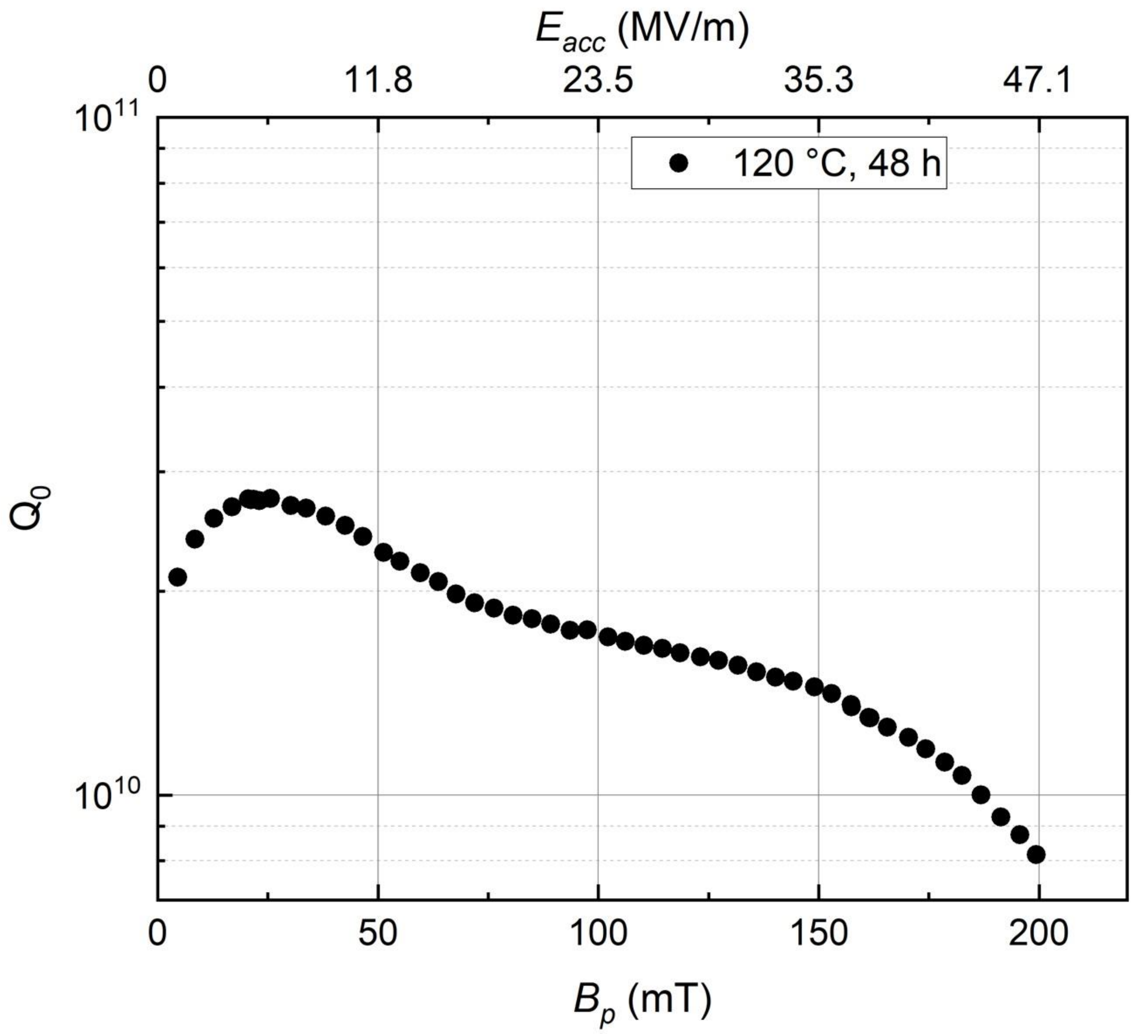
Cavity results

Cavity performance (baseline)

1.3 GHz single-cell cavity

- **EP + 120 °C, 48 hrs (baseline)**

Cavity reached a high gradient of 47.1 MV/m (200 mT)



Cavity performance (mid-T bake)

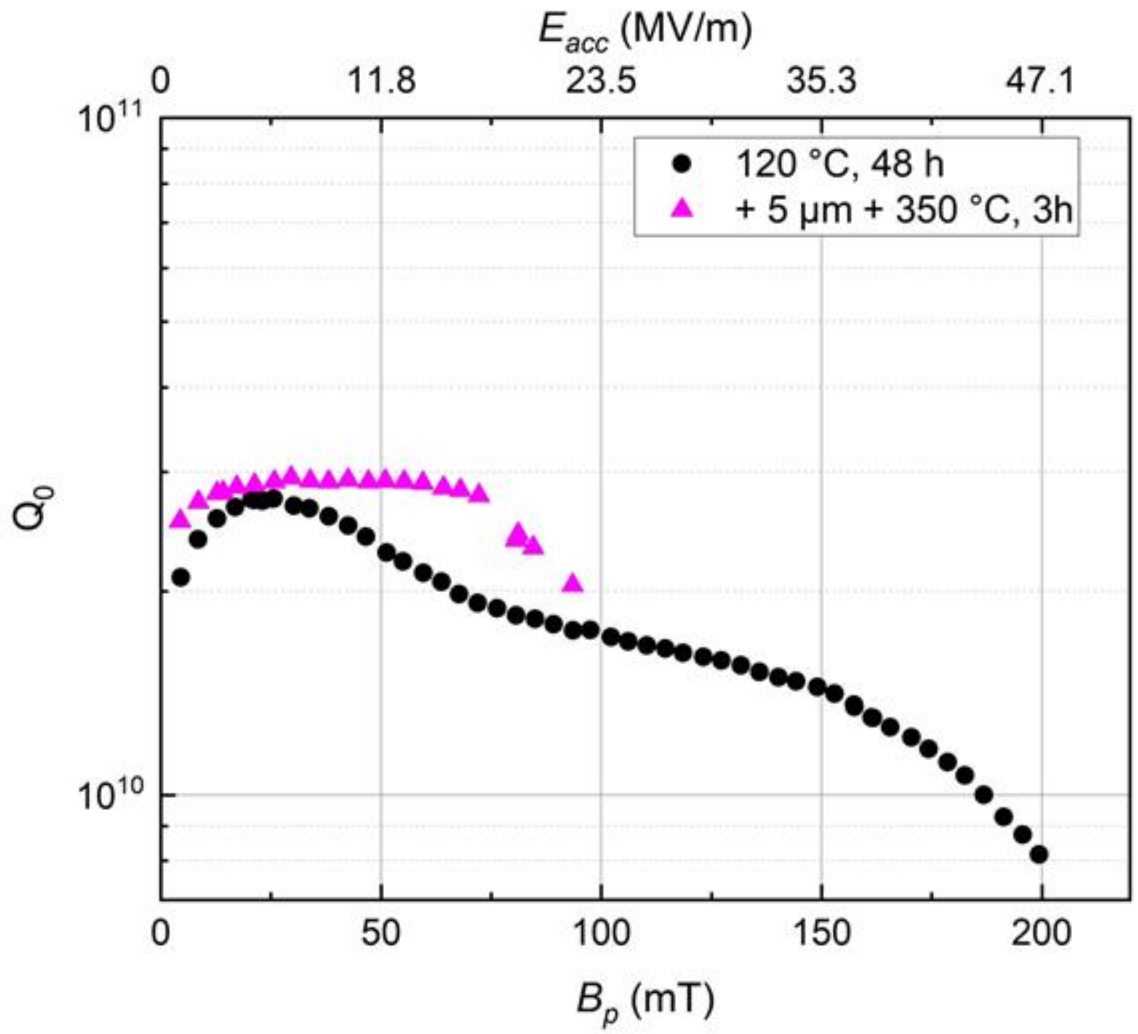
1.3 GHz single-cell cavity

- **EP + 120 °C, 48 hrs (baseline)**

Cavity reached high gradient of 47.1 MV/m (200 mT)

- **Mid-T baking @ 350 °C, 3 hrs**

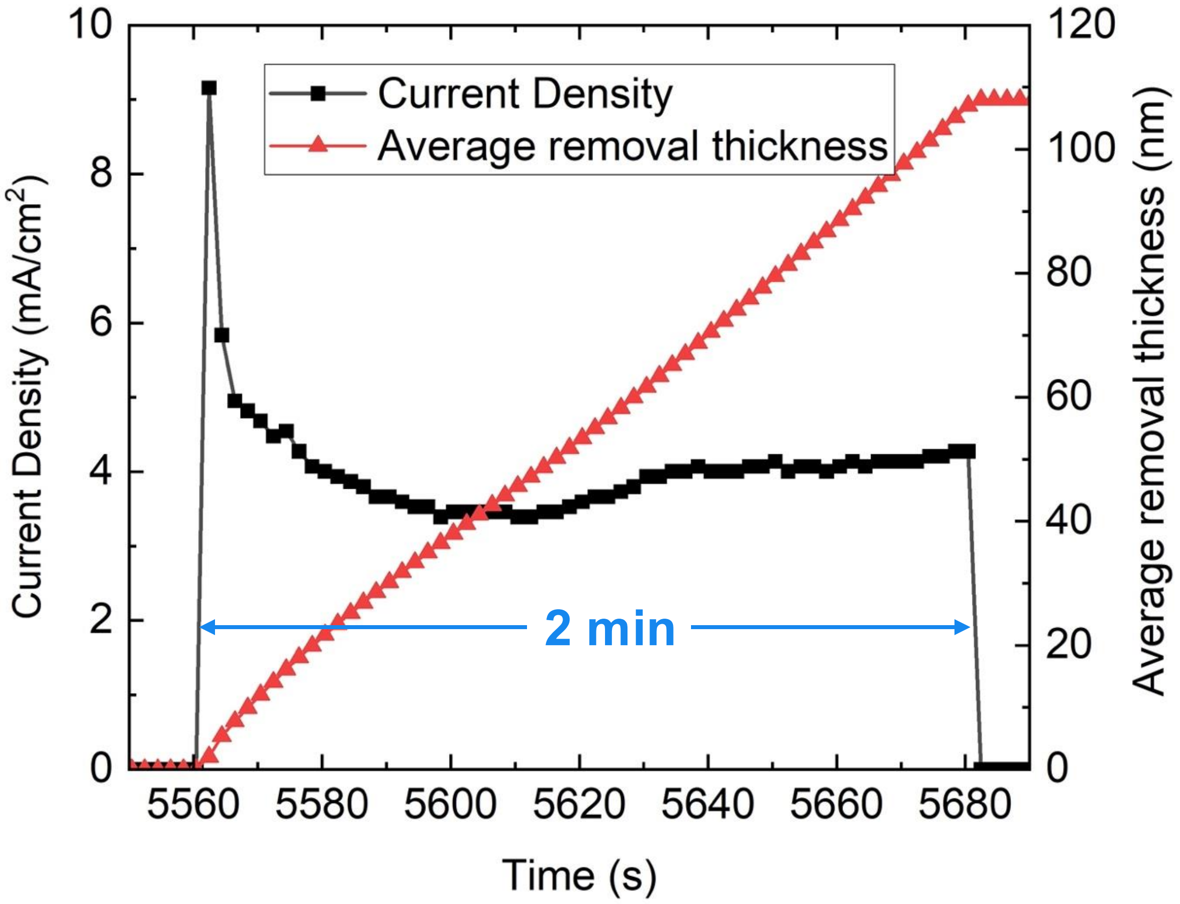
Q value improved, but without a pronounced anti-Q slope. Quench field reduced to 22 MV/m.



Ultralight EP of mid-T baked cavity

1.3 GHz single-cell cavity

- Ultralight EP for target removal of 100 nm was applied to the cavity.
- The cavity surface temperature during EP was maintained below 6 °C.
- EP was accomplished in 2 minutes.
- Average EP removal thickness was **108 nm**.
- EP was well controlled for circumferentially uniform removal.



Cavity performance (mid-T + ultralight EP)

1.3 GHz single-cell cavity

- **EP + 120 °C, 48 hrs (baseline)**

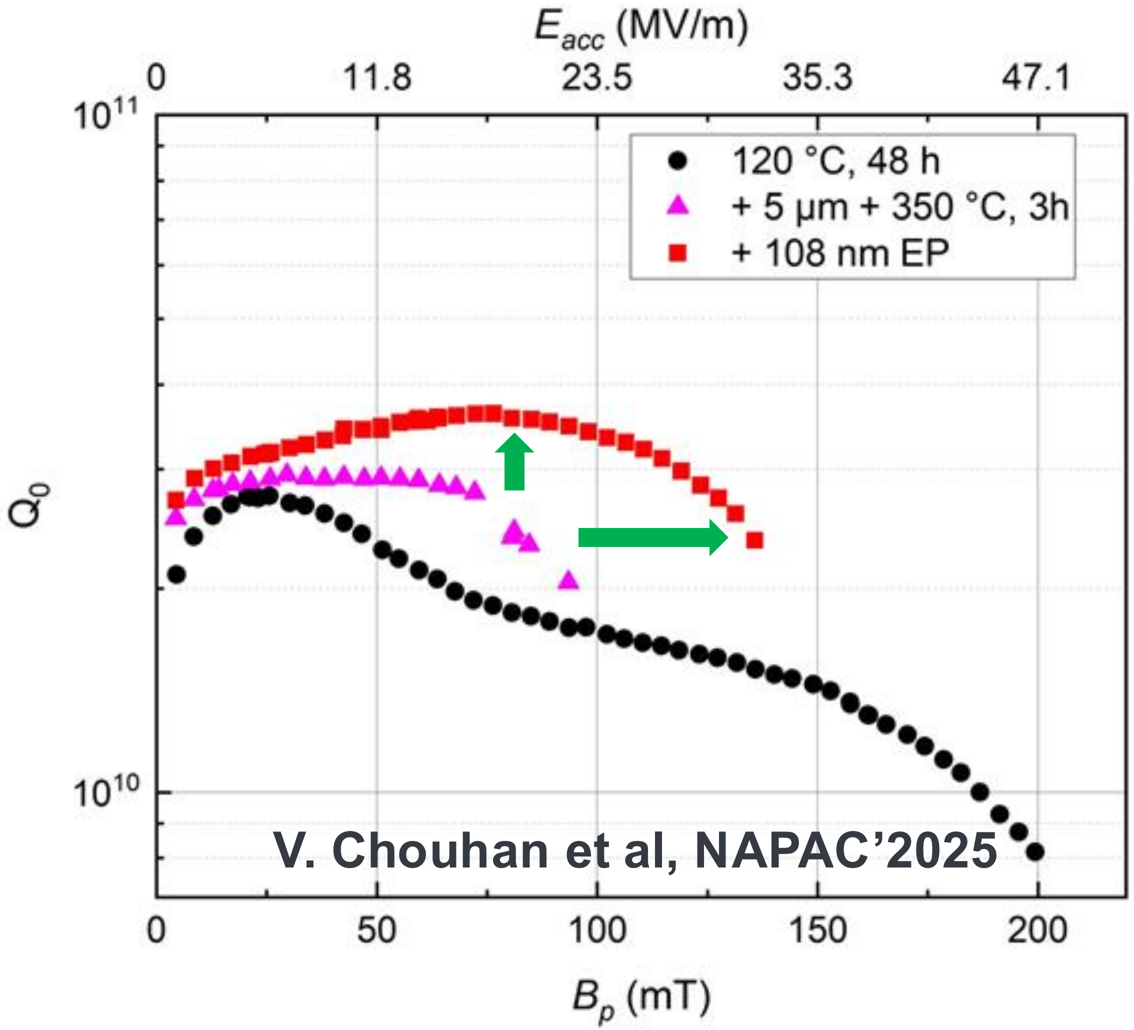
Cavity reached a high gradient of 47.1 MV/m (200 mT)

- **Mid-T baking @ 350 °C, 3 hrs**

Q value improved, but without a pronounced anti-Q slope. Quench field reduced to 22 MV/m.

- **Ultralight EP for 108 nm**

Q-value improved with an apparent anti-Q slope. Quench field also improved to 32 MV/m.



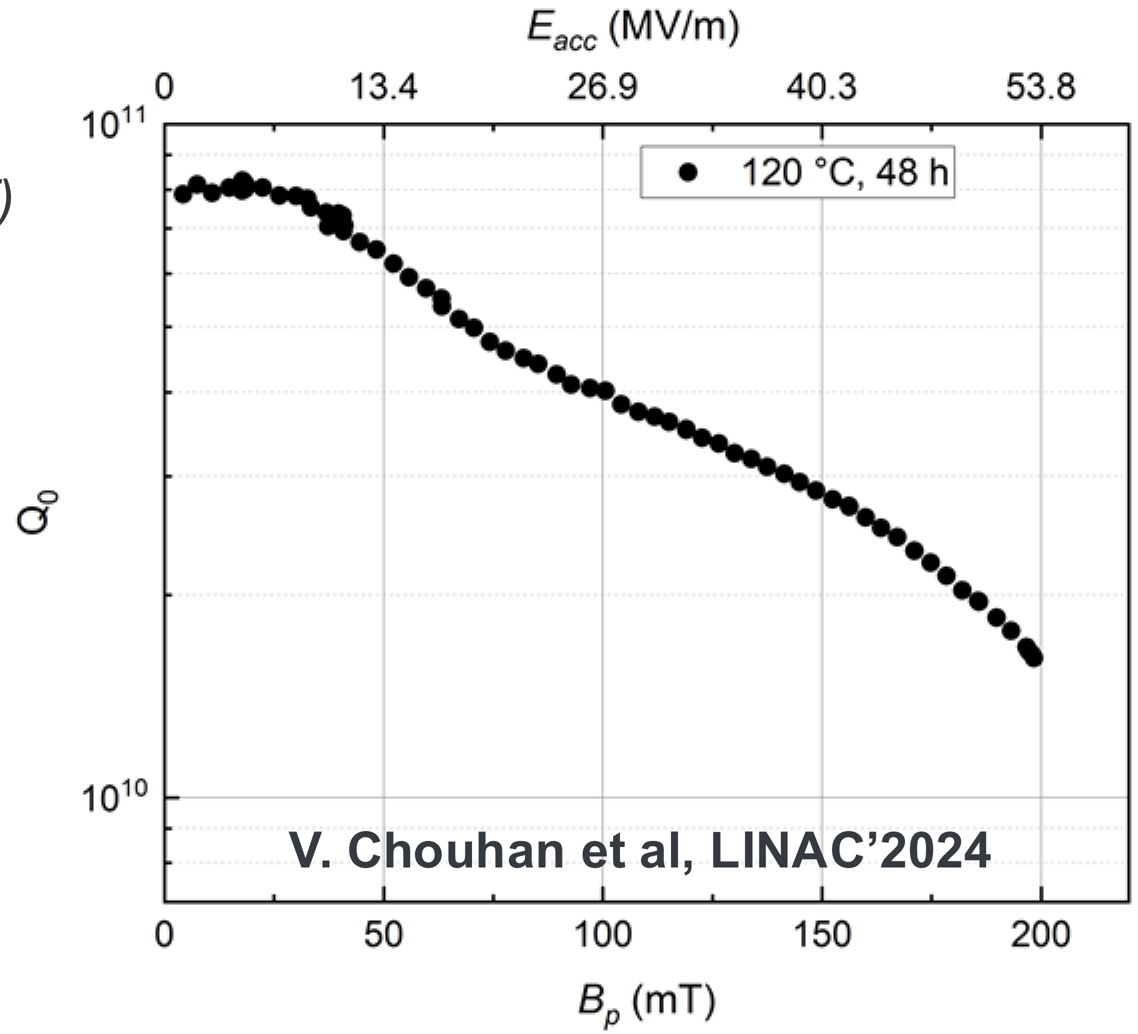
- **The result confirmed that carbide precipitates degraded the cavity performance.**
- **Ultralight EP removal improved both gradient and Q value, and it also delayed the onset field for Q-slope.**

Cavity performance (baseline)

650 MHz single-cell cavity

- **EP + 120 °C, 48 hrs (baseline)**

Cavity reached a high gradient of 53.3 MV/m (~198 mT)



Cavity performance (mid-T bake)

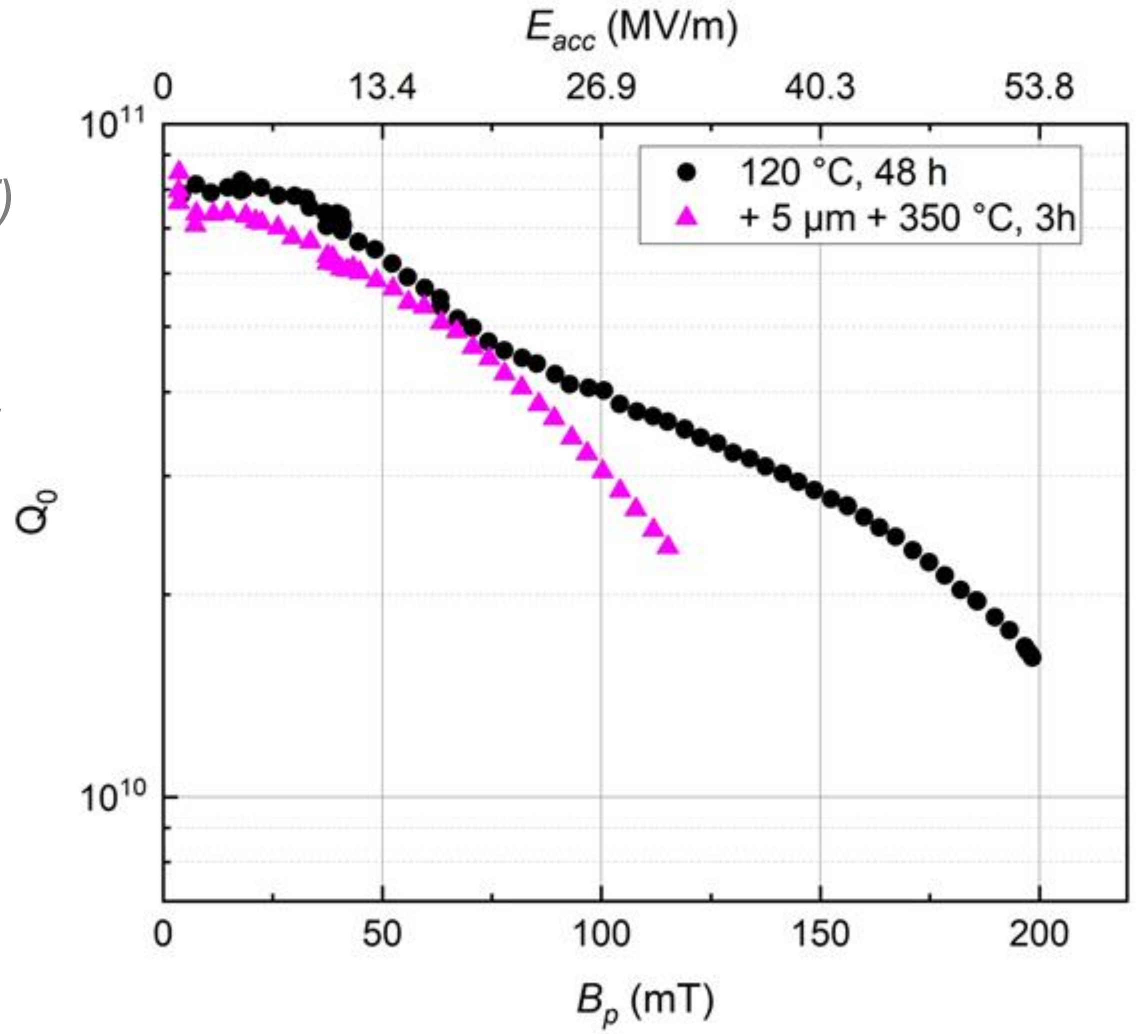
650 MHz single-cell cavity

- **EP + 120 °C, 48 hrs (baseline)**

Cavity reached a high gradient of 53.3 MV/m (~198 mT)

- **Mid-T baking @ 350 °C, 3 hrs**

Q value was found even lower than that in the baseline. Quench field reduced to 33.3 MV/m.



Cavity performance (mid-T + ultralight EP)

650 MHz single-cell cavity

- **EP + 120 °C, 48 hrs (baseline)**

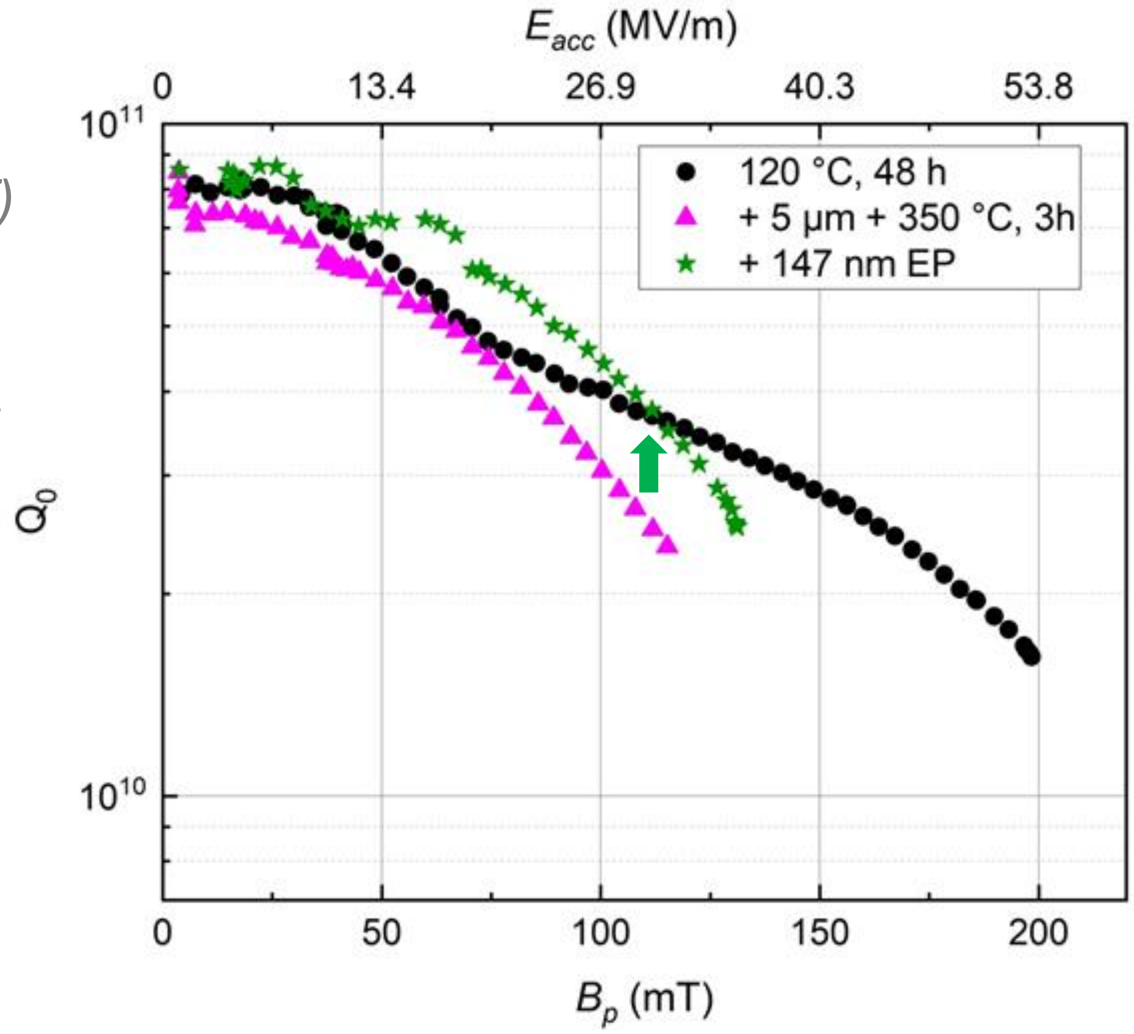
Cavity reached a high gradient of 53.3 MV/m (~198 mT)

- **Mid-T baking @ 350 °C, 3 hrs**

Q value was found even lower than that in the baseline. Quench field reduced to 33.3 MV/m.

- **Ultralight EP step-1 for 147 nm**

Q-value improved after ultralight EP. Quench field improved marginally.



Cavity performance (mid-T + ultralight EP)

650 MHz single-cell cavity

- **EP + 120 °C, 48 hrs (baseline)**

Cavity reached a high gradient of 53.3 MV/m (~198 mT)

- **Mid-T baking @ 350 °C, 3 hrs**

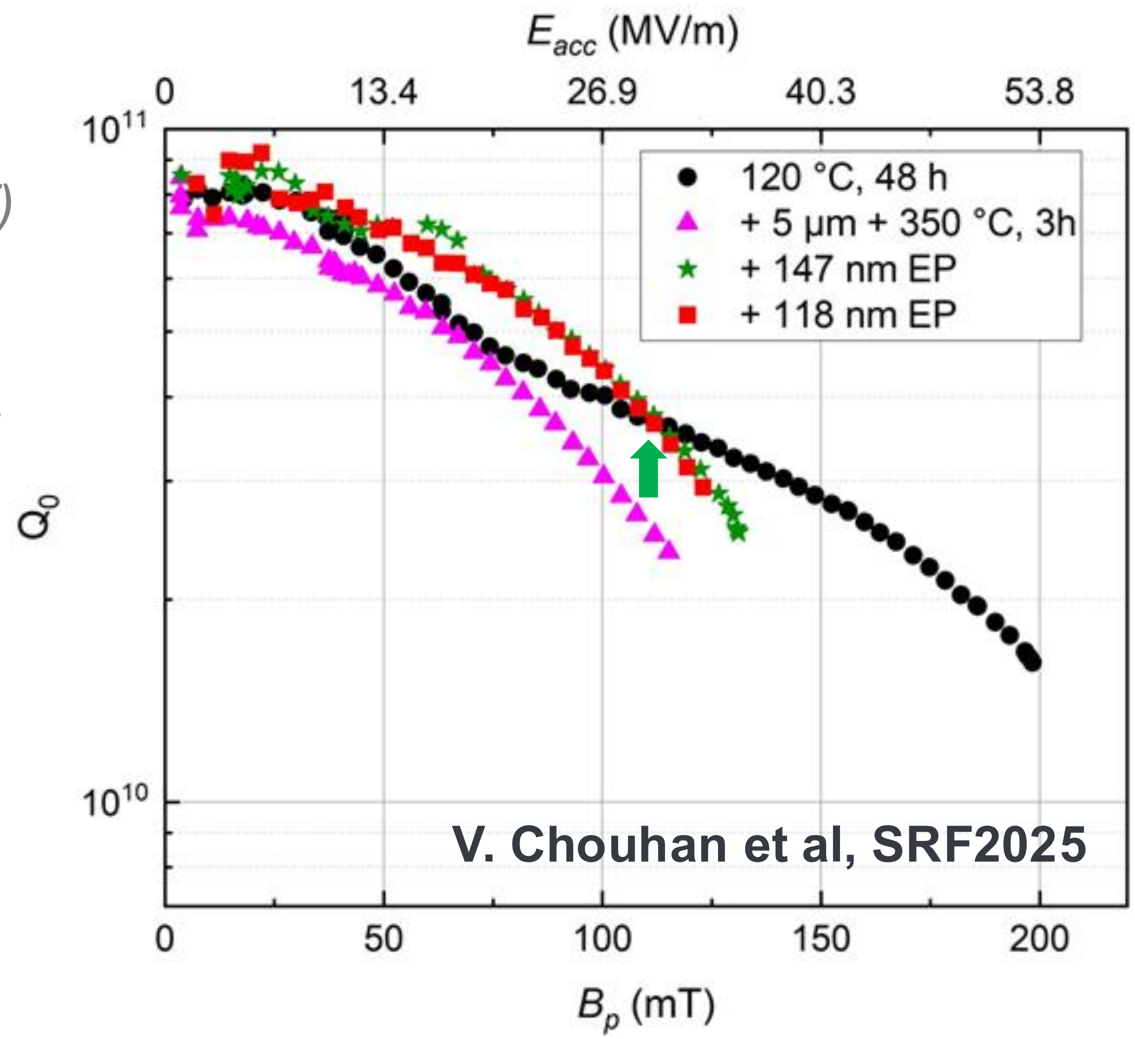
Q value was found even lower than that in the baseline. Quench field reduced to 33.3 MV/m.

- **Ultralight EP step-1 for 147 nm**

Q-value improved after ultralight EP. Quench field improved marginally.

- **Ultralight EP step-2 for 118 nm**

No further improvement after the second EP step.



- **The ultralight EP effect was demonstrated on the 650 MHz cavity through an improvement in its Q value.**
- **An additional ultralight EP step did not further improve performance, indicating that the top RF layer with carbide precipitates was responsible for poor performance after mid-T baking.**

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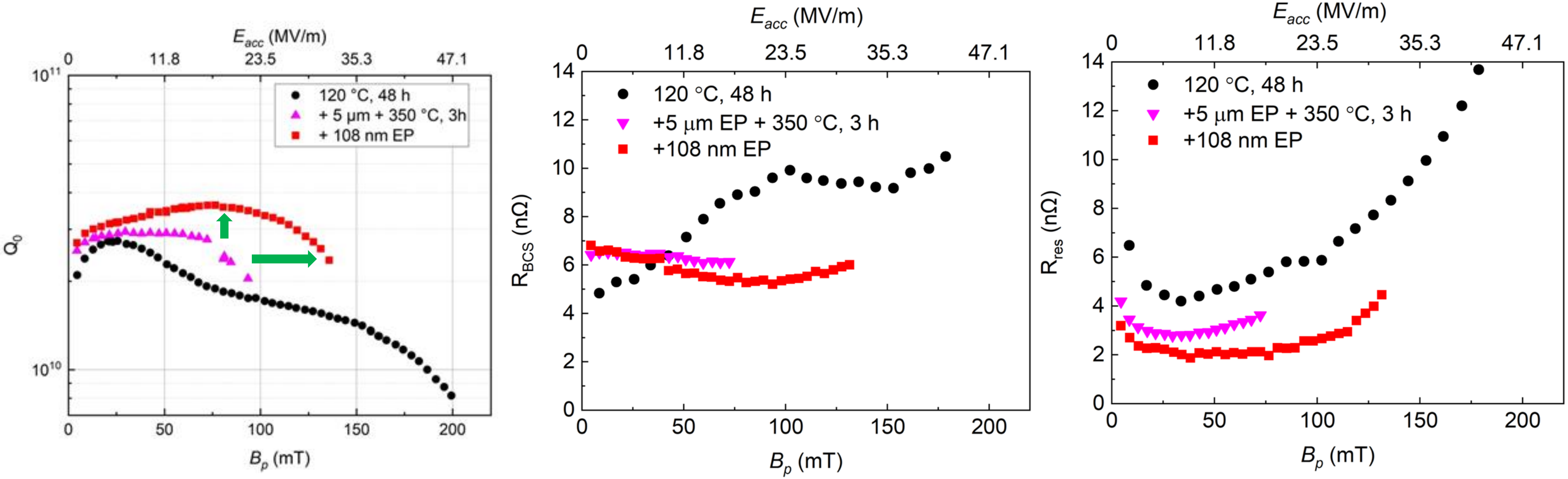
Cavity surface resistance

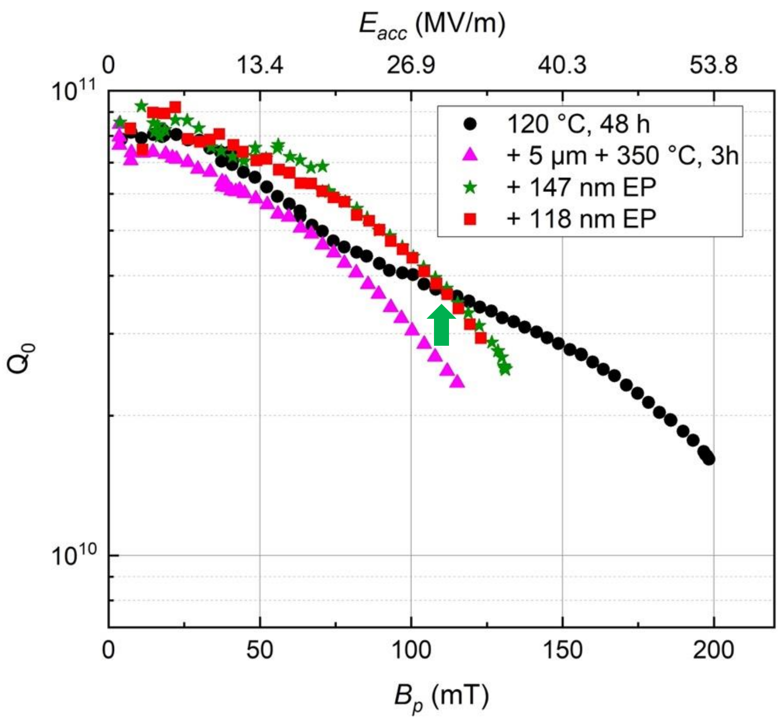
1.3 GHz single-cell cavity

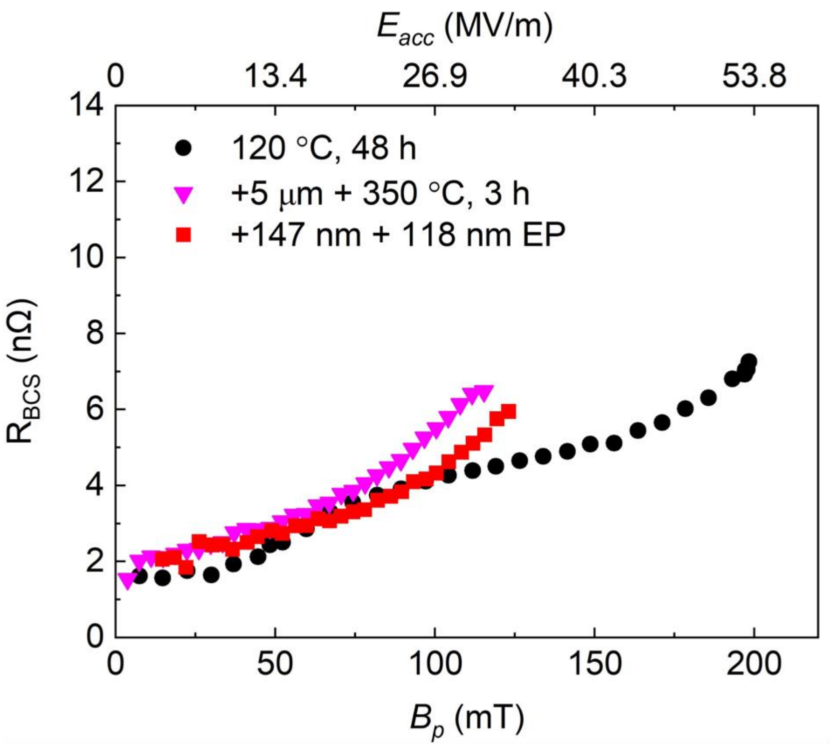


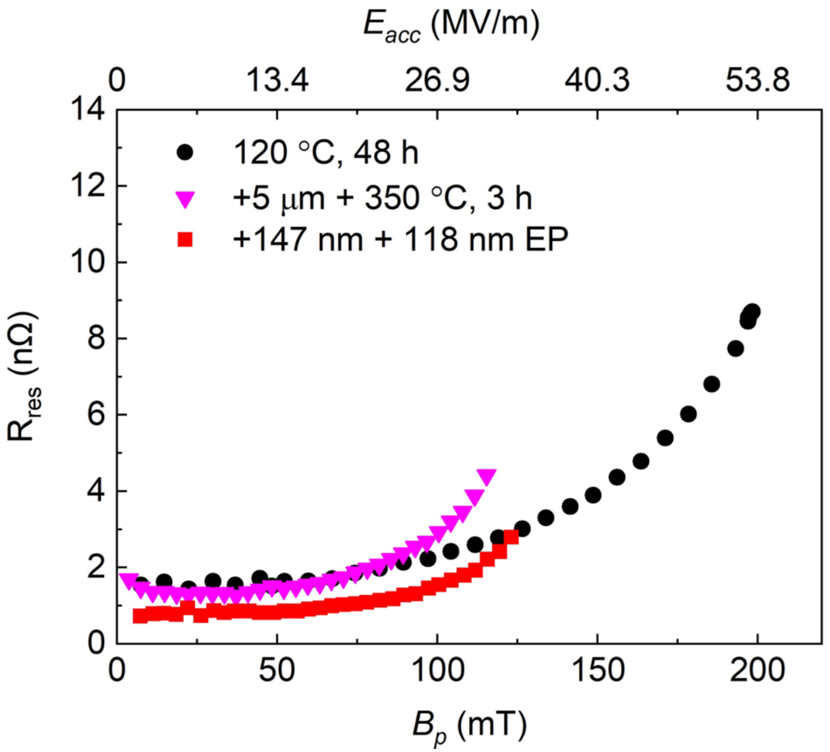
- Carbides primarily affected residual resistance, which contributed to a lower Q value.
- Ultralight EP after mid-T baking significantly reduced residual resistance.
- BCS resistance also decreased, as visible in the higher field range.

Cavity surface resistance

650 MHz single-cell cavity





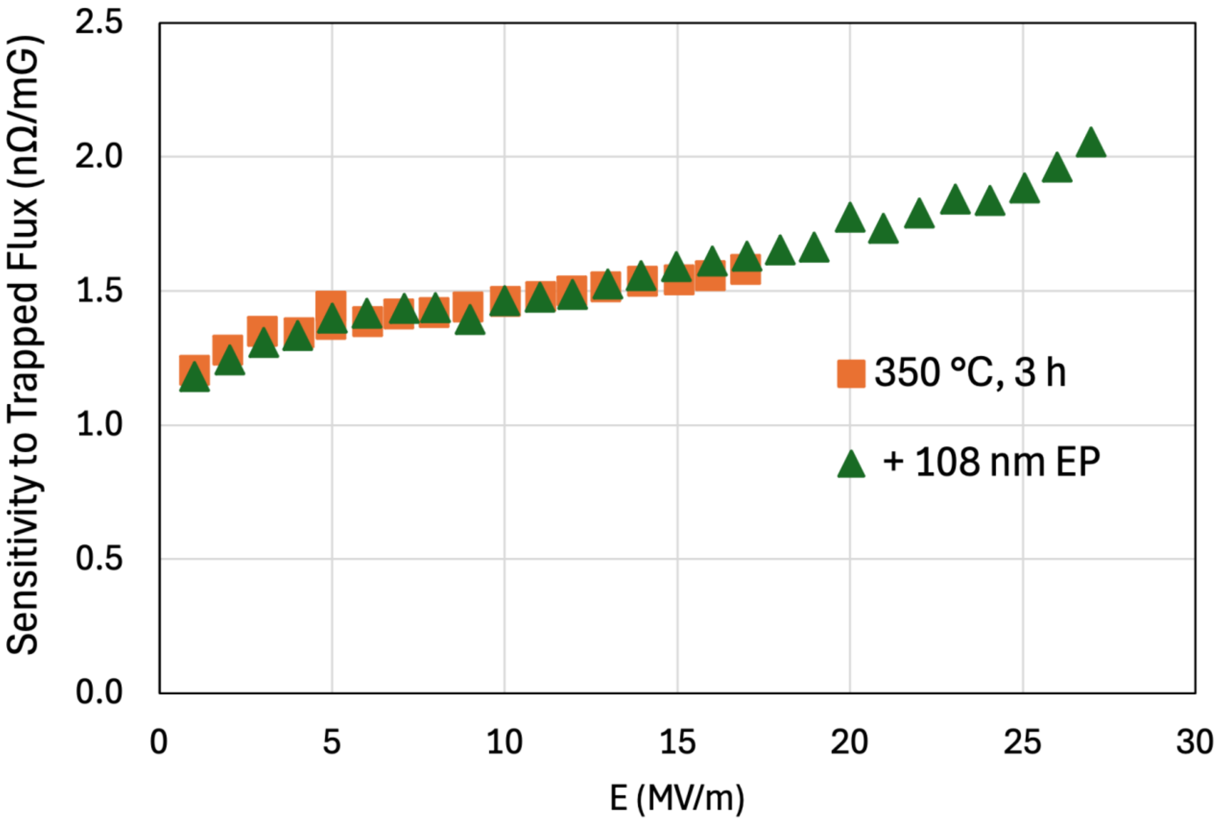


- Ultralight EP effect was similar on the 650 MHz cavity also.
- Residual resistance decreased after ultralight EP, while BCS showed a lower trend for B_p > 50 mT.
- The effect of carbides on the surface resistances was higher in a higher field range (> 100 mT), potentially leading to a high field Q-slope.

Sensitivity to Trapped Flux

1.3 GHz Cavity

- The cavity was also tested with a trapped external magnetic field to measure sensitivity to the trapped flux.
- The sensitivities before and after ultralight EP were similar, suggesting that NbC may not change the sensitivity to trapped flux.



Summary

- Mid-T baking study was performed on Nb samples and cavities.
- The results indicated that niobium carbides formed on the surface during mid-T baking conducted at 350 °C for 3 hours, accumulating within the top RF layer.
- An ultralight EP process was developed to selectively remove this top RF layer and was applied to 1.3 GHz and 650 MHz single-cell cavities after mid-T baking.
- Both cavities showed significant performance improvement following ultralight EP, suggesting that carbides/contaminants removal is beneficial.
- Further study is required to get statistics and to evaluate carbide and ultralight EP effects on 300 °C baked cavities.

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