Field Emission and Voltage Breakdown
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Outline of Two Talks/Today and Tomorrow

• Conclusion
  A picture of the evolution from
  field emission -> voltage breakdown

• Evidence that field emission sites arise from
  microparticle contaminants
  RF and DC
  Apparatus used to find/analyze emitters

• Evidence that breakdown sites arise from
  contaminants
  RF and DC
  Apparatus used to find/analyze breakdown sites

• The smoking gun
  Intentionally introduced particles that cause
  breakdown
  RF and DC

• Evidence that gases are involved in breakdown
  RF and DC
• A numerical simulation of the picture for the evolution of breakdown Movie in working group?

• More about field emitters
  Not all particles are emitters
  Role of Microgeometry
  Role of condensed gas

• What to do?
  Avoid microparticles
  Extensive bake to reduce adsorbed layer
  Avoid exposure to poor vacuum
  => use windows to isolate accelerating structure vacuum
• Evidence that field emission sites arise from microparticle contaminants
  RF and DC
  Apparatus used to find/analyze emitters
Occasionally it is even possible to detect the presence of the site due to higher rf loss.
Field Emission in RF Cavities

Dominant Gradient Limitation

$E_{pk} = 23.7 \text{ MV/m}$

$\Delta T$

Temperature Change (Arb. Units)

Thermometers Locations

Cavity Boundary

3 GHz

1.5 GHz
Fig. 41
Simulation of field emission in an rf cavity.
(a) Electron trajectories in one rf period from a hypothetical emitter.
(b) Corresponding impact current density profiles at the highest fields.
(c) Impact energy profiles.
(d) Power density profiles.
(e) Simulated temperature maps (at same azimuth as emitter location).
(f) Fowler Nordheim plot of peak temperature rise, showing \( \beta \).
6.20: (a) Temperature signal of the circled site in Figure 6.19 as a function of $E_{pk}$. No significant changes in $\Delta T$ were observed. (b) Fowler-Nordheim plot of the same temperature data at $E_{pk} = 18$ MV/m.
What kind of emitters are likely to process?

![Graph showing current density vs. current](image)

- **Critical Current Density**: \( \approx 10^{11} \text{ A/m}^2 \)
- **Critical Current**: \( \approx 50-100 \mu\text{A} \)
(b) SEM photograph of the site associated with the temperature signals shown in part (a).

Figure 4.25. An example of an SEM located surface site associated with a field emission site which was not processable through HPP.
Elemental Analysis Using Auger Spectroscopy.
The experience with DC field emission suggests that small particles are the main origin of field emitted current and that geometric effects determine the field enhancement factor. It seems plausible that the same parameters are also important for radiofrequency field emission, but it cannot be excluded that other parameters might be relevant, too. Therefore, field emission studies under radiofrequency conditions are necessary. At Cornell many field emitters in cavities have been localized by temperature mapping. After dismounting (or
• Evidence that breakdown sites arise from contaminants
  RF and DC
  Apparatus used to find/analyze breakdown sites
Before low power event; 
\[ E_{peak} = 29.6 \text{ MV/m}. \]

(b). Following low power event; 
\[ E_{peak} = 31.7 \text{ MV/m}. \]
The Mark II cavity design. The baseplate is joined to the cavity using an indium -ring.
Impurities were found in every site examined.

From the mushroom cavity using Auger
• The smoking gun
  Intentionally introduced particles that cause breakdown
  RF and DC