ALD Update

J. Norem
ANL/HEP

NFMCC Friday
3/7/8

Quick Review

NFMCC and CLIC

ALD experiments

Two approaches:

Ours

Breakdown is driven by Electric fields (it occurs where E is maximum).
Field emission measurements give local fields of ~8 GV/m.
These fields produce tensile stresses of 200 - 400 MPa (~macro. tensile strength)
Fatigue eventually drives the failures (Tens. str. in 50 nm samples is complicated)
The operating gradient of cavities is determined by surface damage.
The solution:

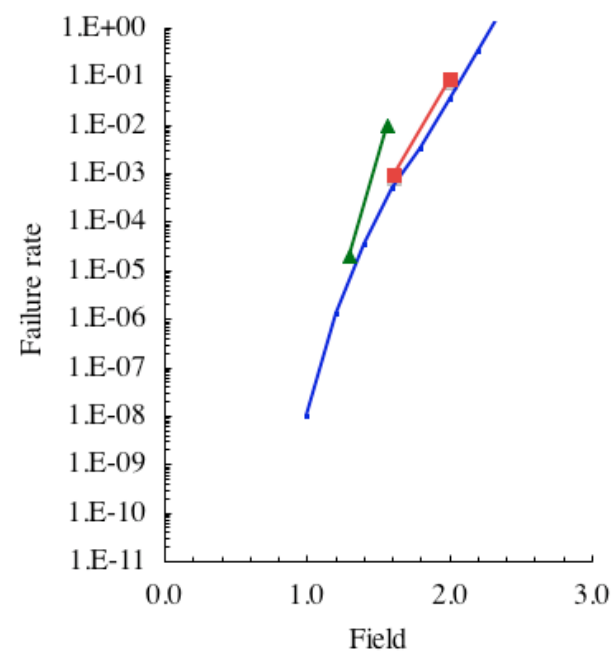
- Smooth surfaces
- Perhaps layered conductors

SLAC / CERN

Failures are caused by melting and fatigue
The solution:

- Harder materials

Everyone likes fatigue as an element in breakdown.



Just for the record.

Feynman Lectures, book 2

6–11 High-voltage breakdown

We would like now to discuss qualitatively some of the characteristics of the fields around conductors. If we charge a conductor that is not a sphere, but one that has on it a point or a very sharp end, as, for example, the object sketched in Fig. 6–14, the field around the point is much higher than the field in the other regions. The reason is, qualitatively, that charges try to spread out as much as possible on the surface of a conductor, and the tip of a sharp point is as far away as it is possible to be from most of the surface. Some of the charges on the plate get pushed all the way to the tip. A relatively small *amount* of charge on the tip can still provide a large surface *density;* a high charge density means a high field just outside.

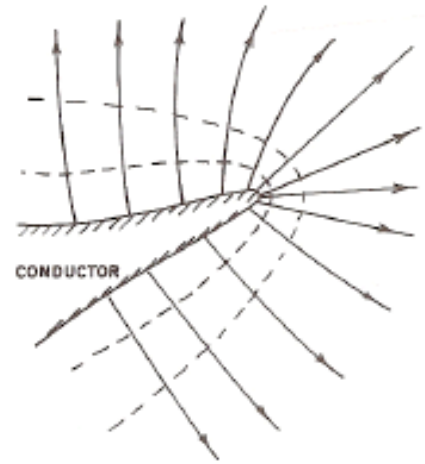


Fig. 6–14. The electric field near a sharp point on a conductor is very high.

One way to see that the field is highest at those places on a conductor where the radius of curvature is smallest is to consider the combination of a big sphere and a little sphere connected by a wire, as shown in Fig. 6–15. It is a somewhat idealized version of the conductor of Fig. 6–14. The wire will have little influence on the fields outside; it is there to keep the spheres at the same potential. Now, which ball has the biggest field at its surface? If the ball on the left has the radius a and carries a charge Q, its potential is about

$$\phi_1 = \frac{1}{4\pi\epsilon_0}\frac{Q}{a}.$$

(Of course the presence of one ball changes the charge distribution on the other, so that the charges are not really spherically symmetric on either. But if we are interested only in an estimate of the fields, we can use the potential of a spherical charge.) If the smaller ball, whose radius is b, carries the charge q, its potential is about

$$\phi_2 = \frac{1}{4\pi\epsilon_0}\frac{q}{b}.$$

But $\phi_1 = \phi_2$, so

$$\frac{Q}{a} = \frac{q}{b}.$$

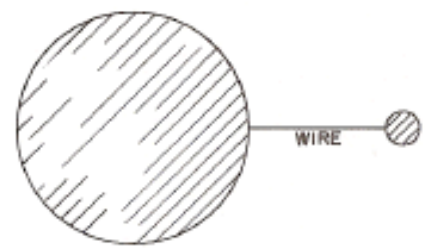


Fig. 6–15. The field of a pointed object can be approximated by that of two spheres at the same potential.

On the other hand, the field at the surface (see Eq. 5.8) is proportional to the surface charge density, which is like the total charge over the radius squared. We get that

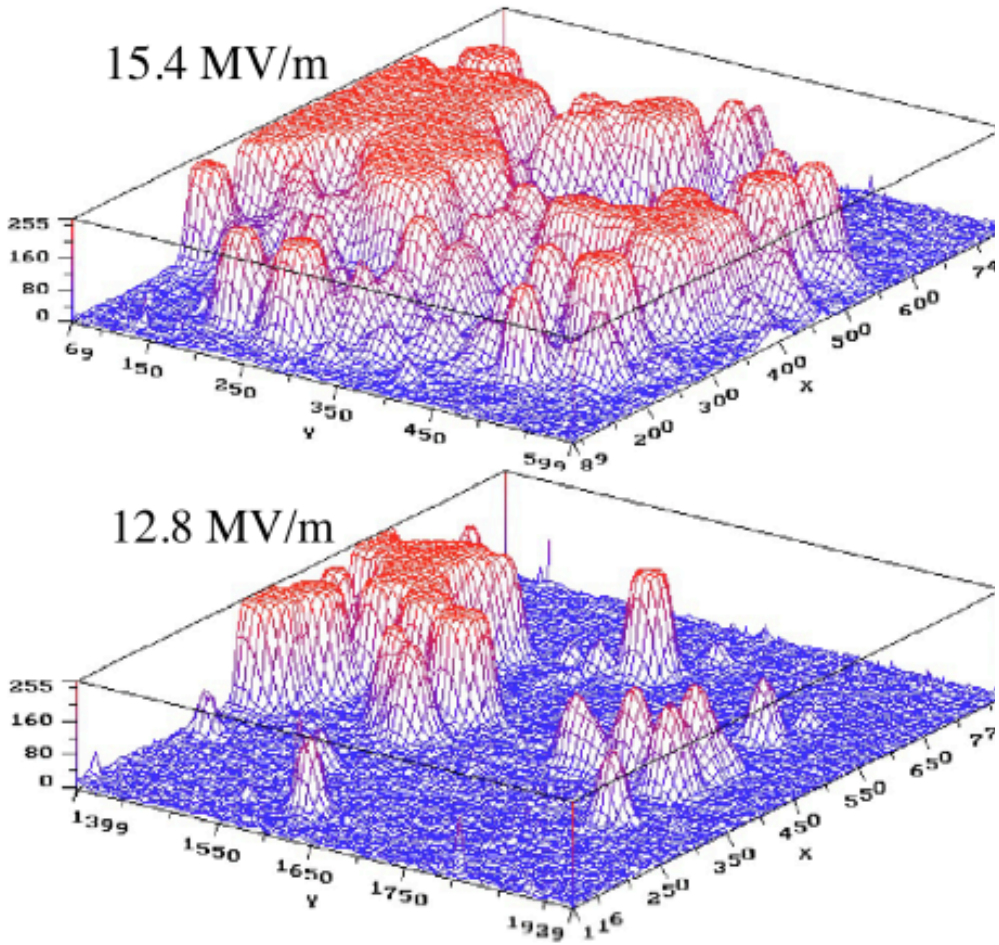
$$\frac{E_a}{E_b} = \frac{Q/a^2}{q/b^2} = \frac{b}{a}. \tag{6.35}$$

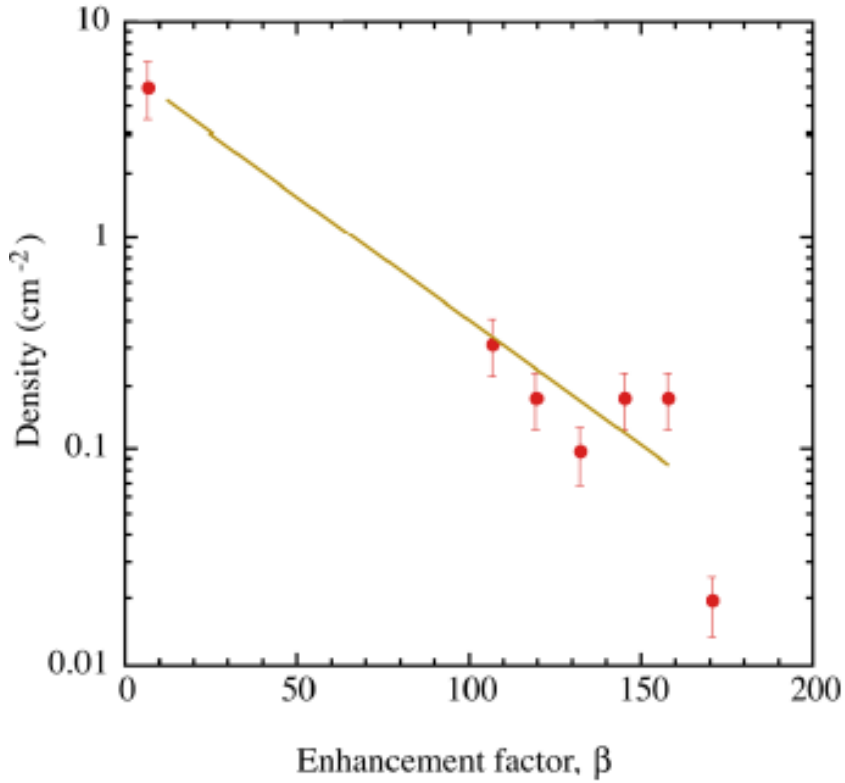
Therefore the field is higher at the surface of the small sphere. The fields are in the inverse proportion of the radii.

This result is technically very important, because air will break down if the electric field is too great. What happens is that a loose charge (electron, or ion) somewhere in the air is accelerated by the field, and if the field is very great, the charge can pick up enough speed before it hits another atom to be able to knock an electron off that atom. As a result, more and more ions are produced. Their motion constitutes a discharge, or spark. If you want to charge an object to a high potential and not have it discharge itself by sparks in the air, you must be sure that the surface is smooth, so that there is no place where the field is abnormally large.

Smoother surfaces should go to higher fields.

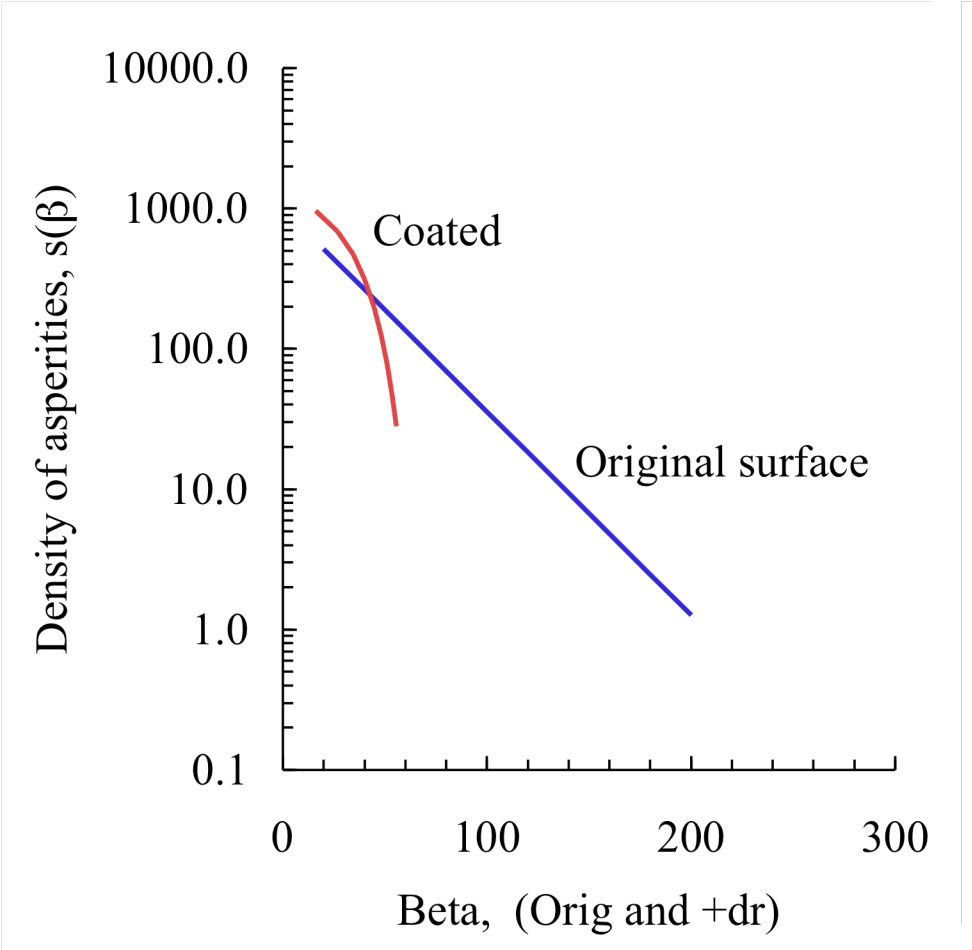
Our data from the 805 cavity show a spectrum of field emitters.

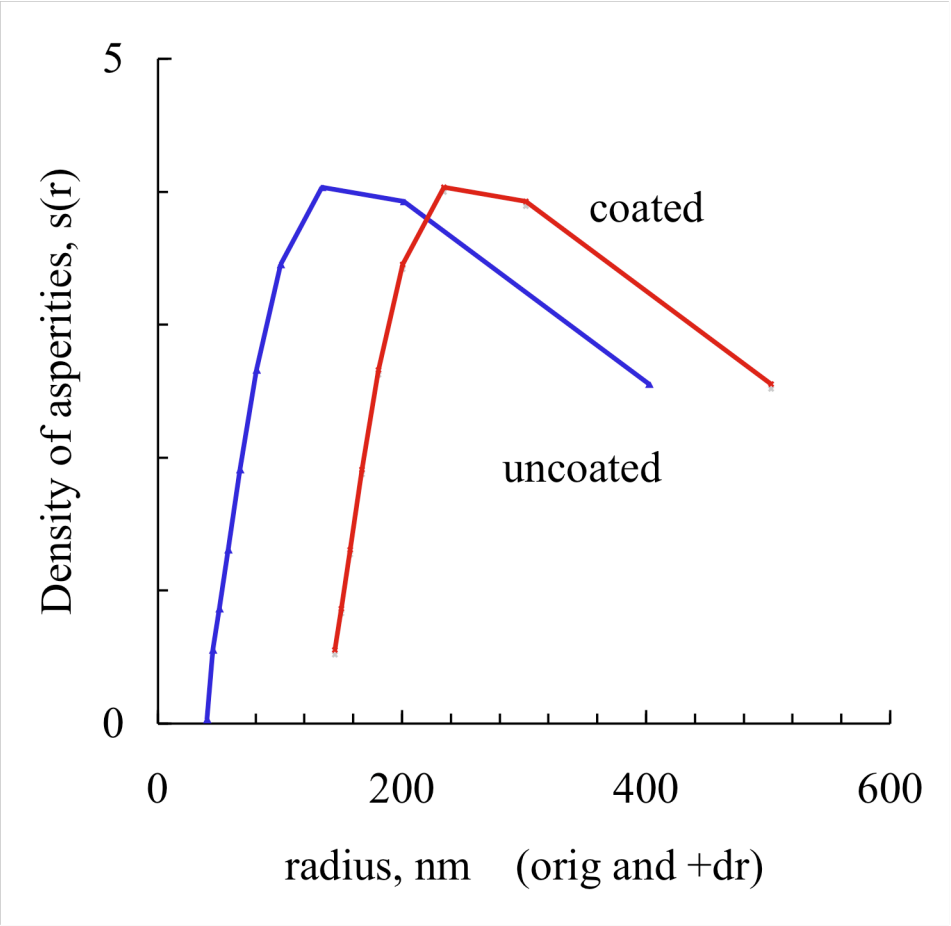




Coating can change the spectrum of enhancements.

- What is the effect of a 100 nm conducting coating?



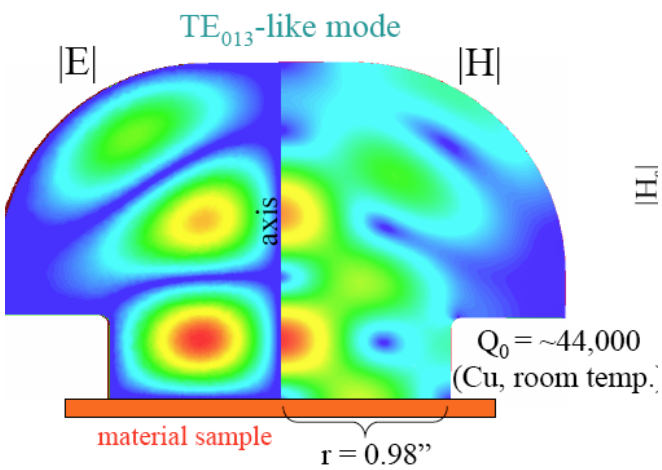


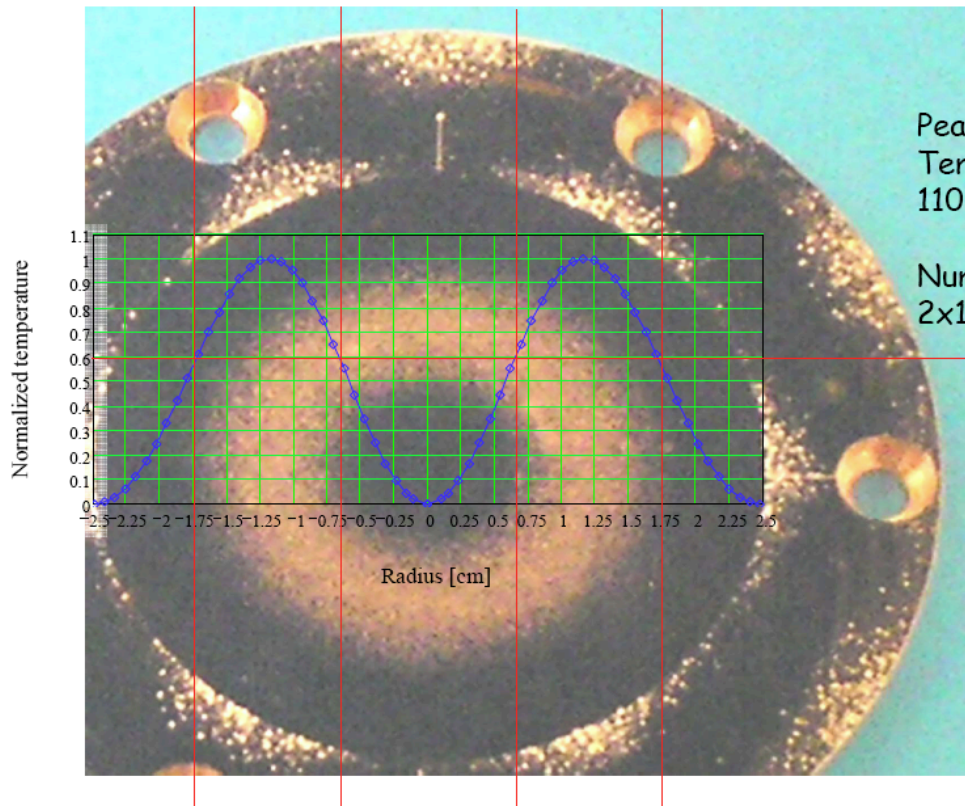
- This should give <u>three times higher</u> rf gradients.

What about pulsed heating?

- A paper by Pritzkau and Siemann in 2002 argued that surface currents will cause heat fluctuations which will cause compressional fatigue and eventually cavity failure.

- Tantawi and Dolgashev see damage from skin currents.





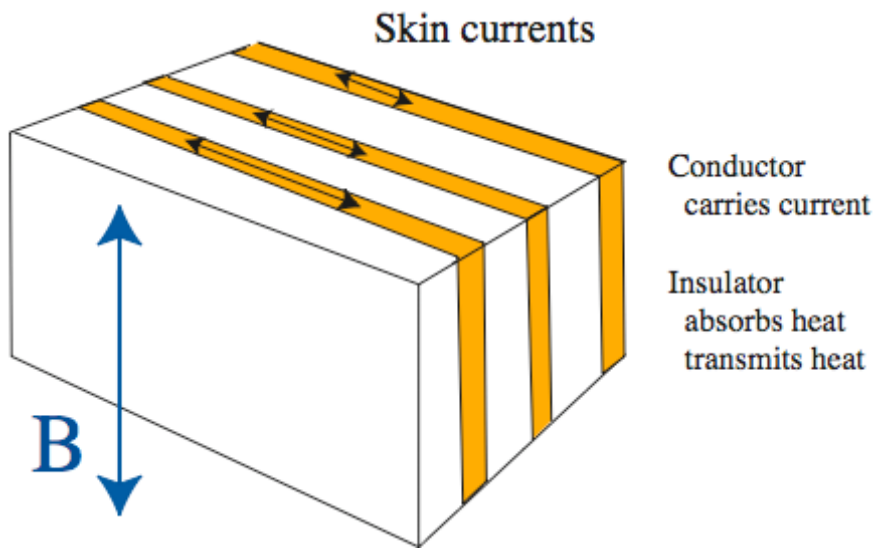
Peak transient
Temperature rise
110 degree Celsius

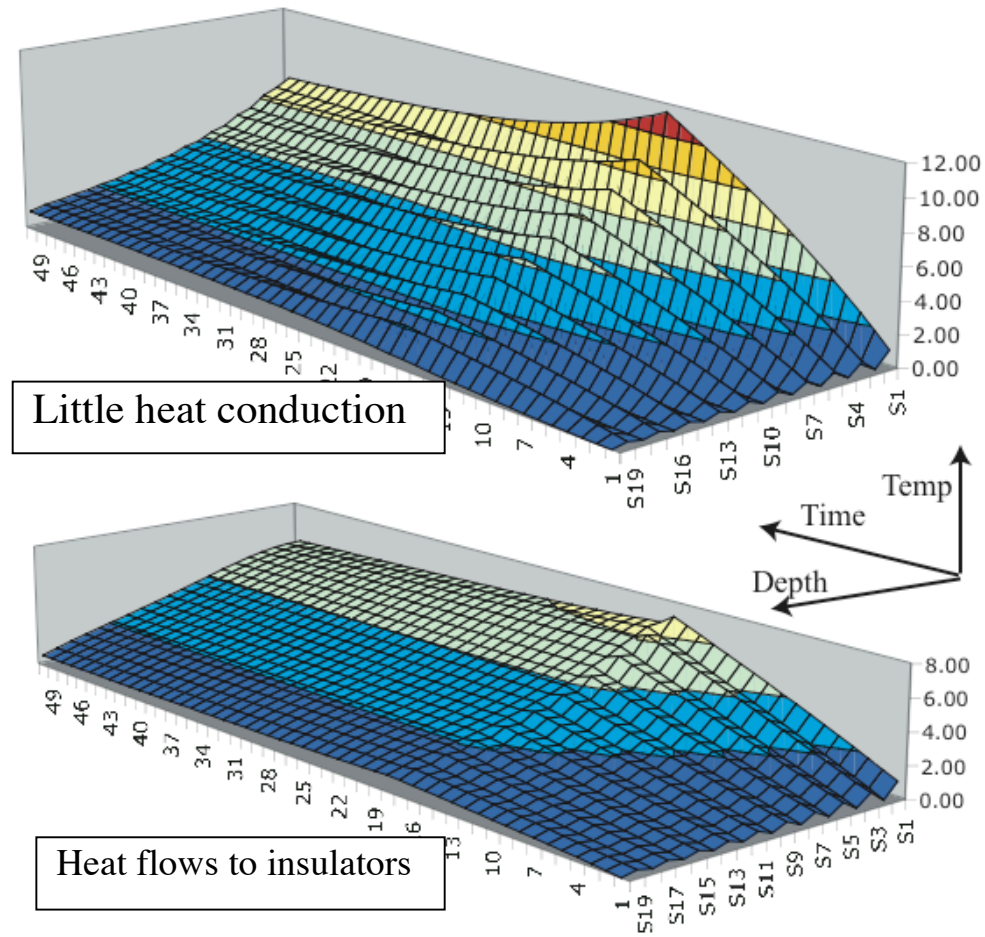
Number of pulses
2×10^6

- High temp ➜ damage

Surface layers can cure pulsed heating, in principle.

- You can build a composite material with higher specific heat.



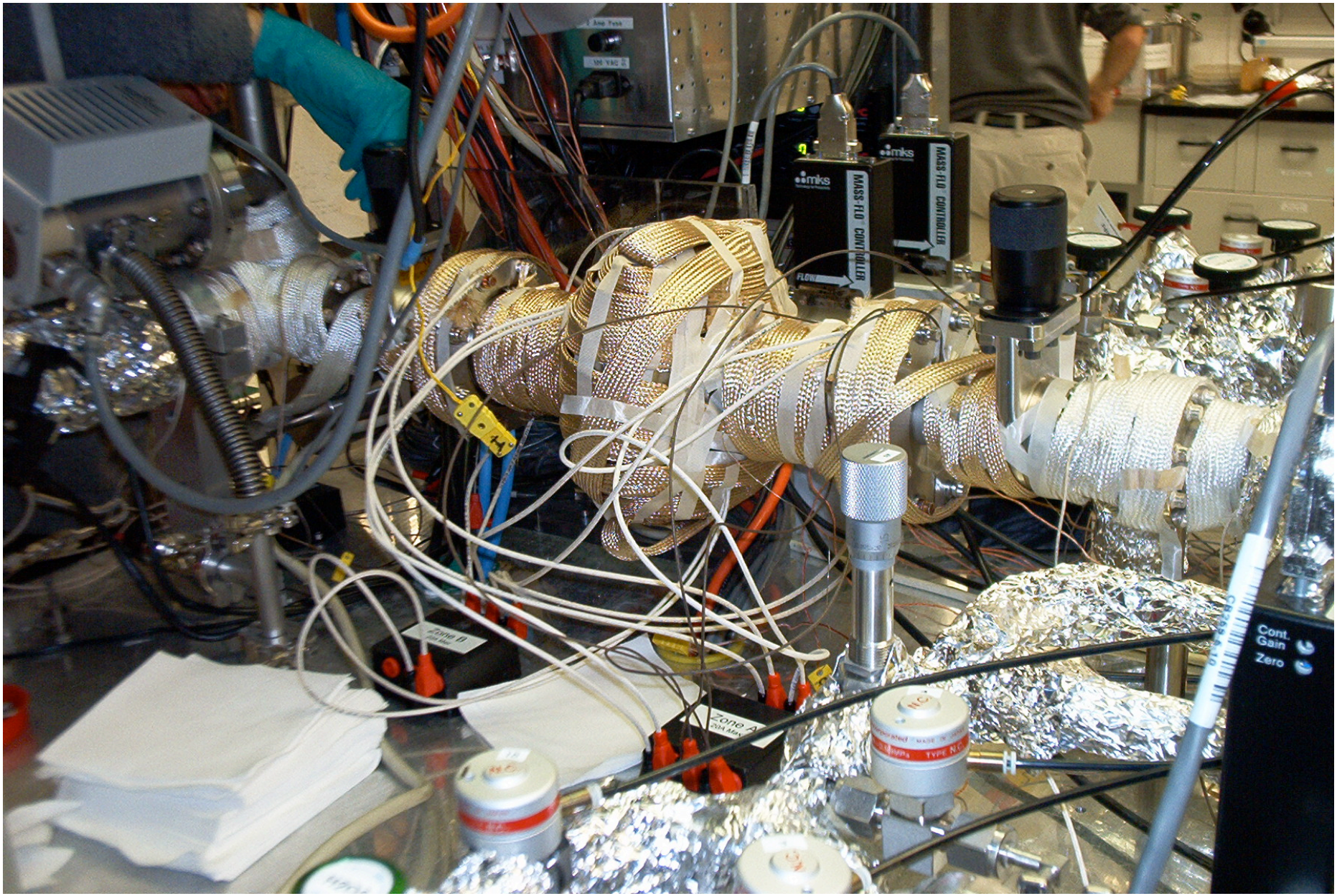


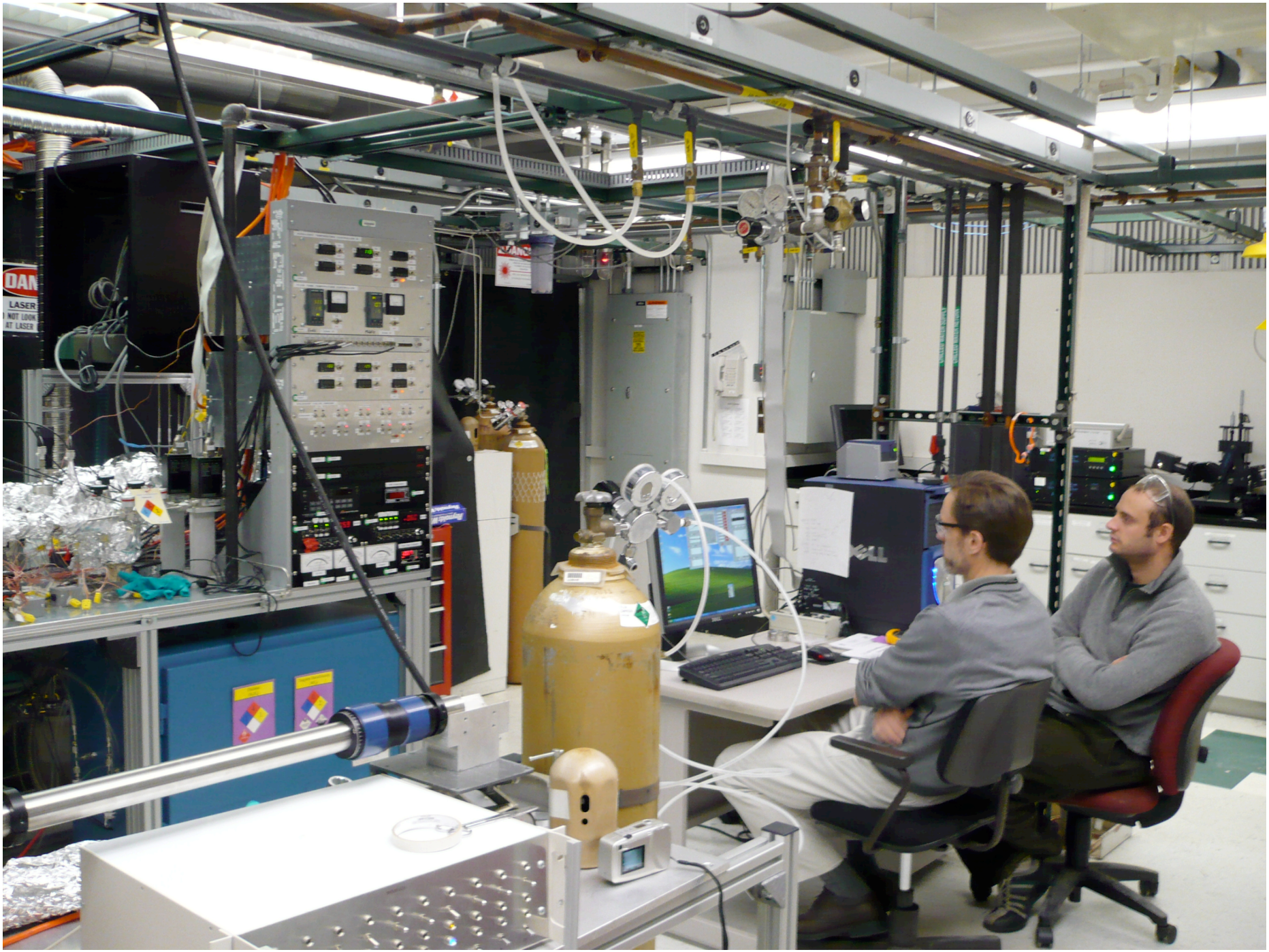
- Less thermal excursion
  Less fatigue
  Longer lifetime

So . . where are the ALD experiments?

- We have submitted a paper to Applied Physics letters explaining how magnetic oxides can cause high field Q-slope (anomalous high field losses).
- We have shown how coating a Niobium cavity with alumina with a high temperature bake (860 C) can eliminate the dangerous oxides. (paper will come soon).
- We have coated a SCRF cavity with alumina.
- We are planning studies of binary superconductors Nb_3Sn, NbN, MgB_2.
- We have a proposal in to DOE/HEP to support a real program.

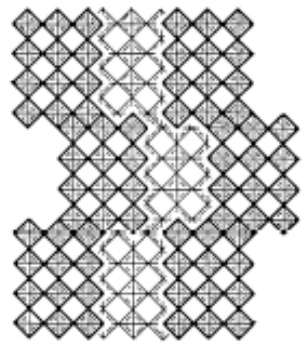
Coating a SCRF single cell cavity.



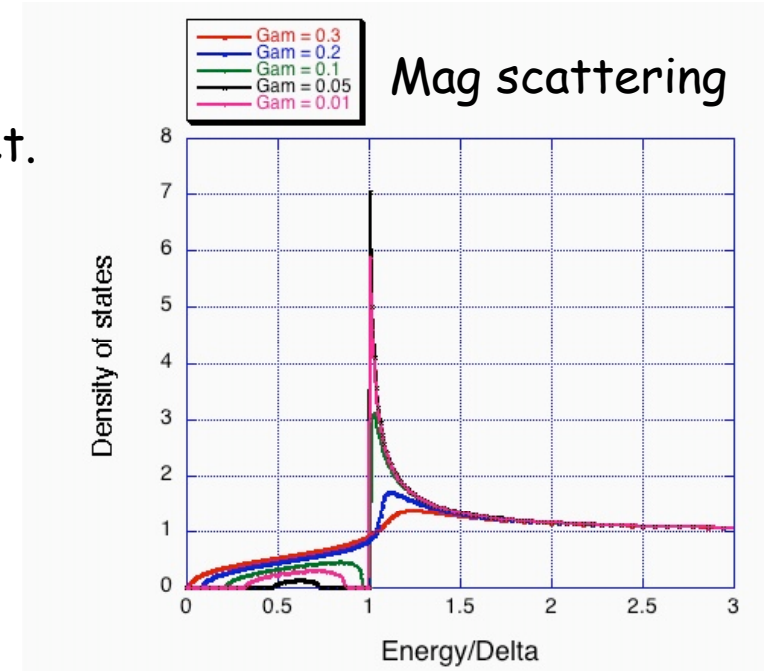

LASER
NOT LOOK
AT LASER

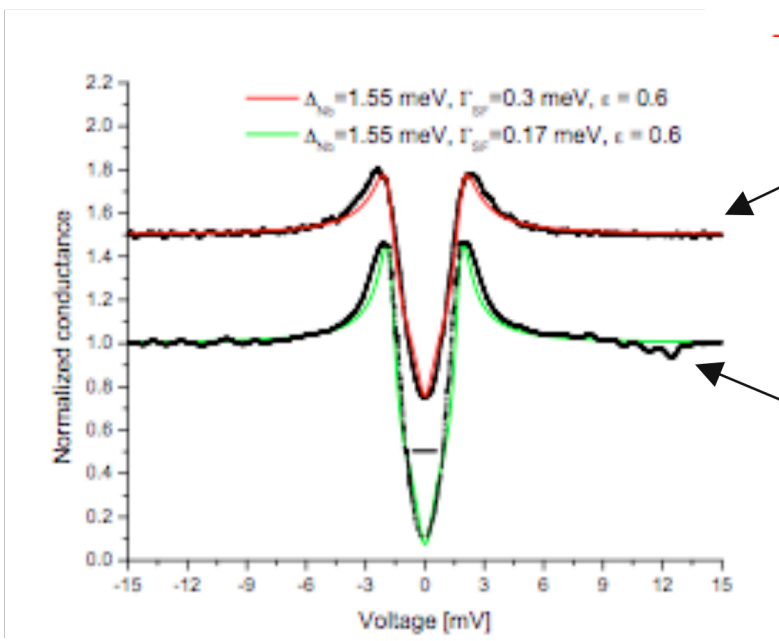
We showed this Jan 11, it is more official now.

- John Zasadzinski explained that his point contact tunneling measurements clearly show that these magnetic oxides can break up Cooper pairs and explain high field Q-Slope.
- Described at SRF2007, submitted to Appl. Phy. Let.
- Strange oxides are involved.



$Nb_{12}O_{29}$





Fit using Shiba theory

Baked Nb Crystal Shows reduced Magnetic scattering

Summary

We are underway.

This may be a general solution to many problems.