RF Pulsed Heating and Bob Siemann

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Introduction

- I was a grad student of Bob's from 1994 to 2001
- I first met Bob in 1994 at an orientation at Stanford for new incoming grad students in physics
- I was immediately captured by Bob's enthusiasm and passion as he described all of the cool things in accelerator physics he was working on
- I joined Bob's group as part of the quarterly rotation that incoming students participate in, but I never rotated out
- Not only did I catch the accelerator physics bug, but after one quarter I could already perceive what a terrific mentor Bob was and I could not let go of a good thing

ARDB and 1 GeV/m

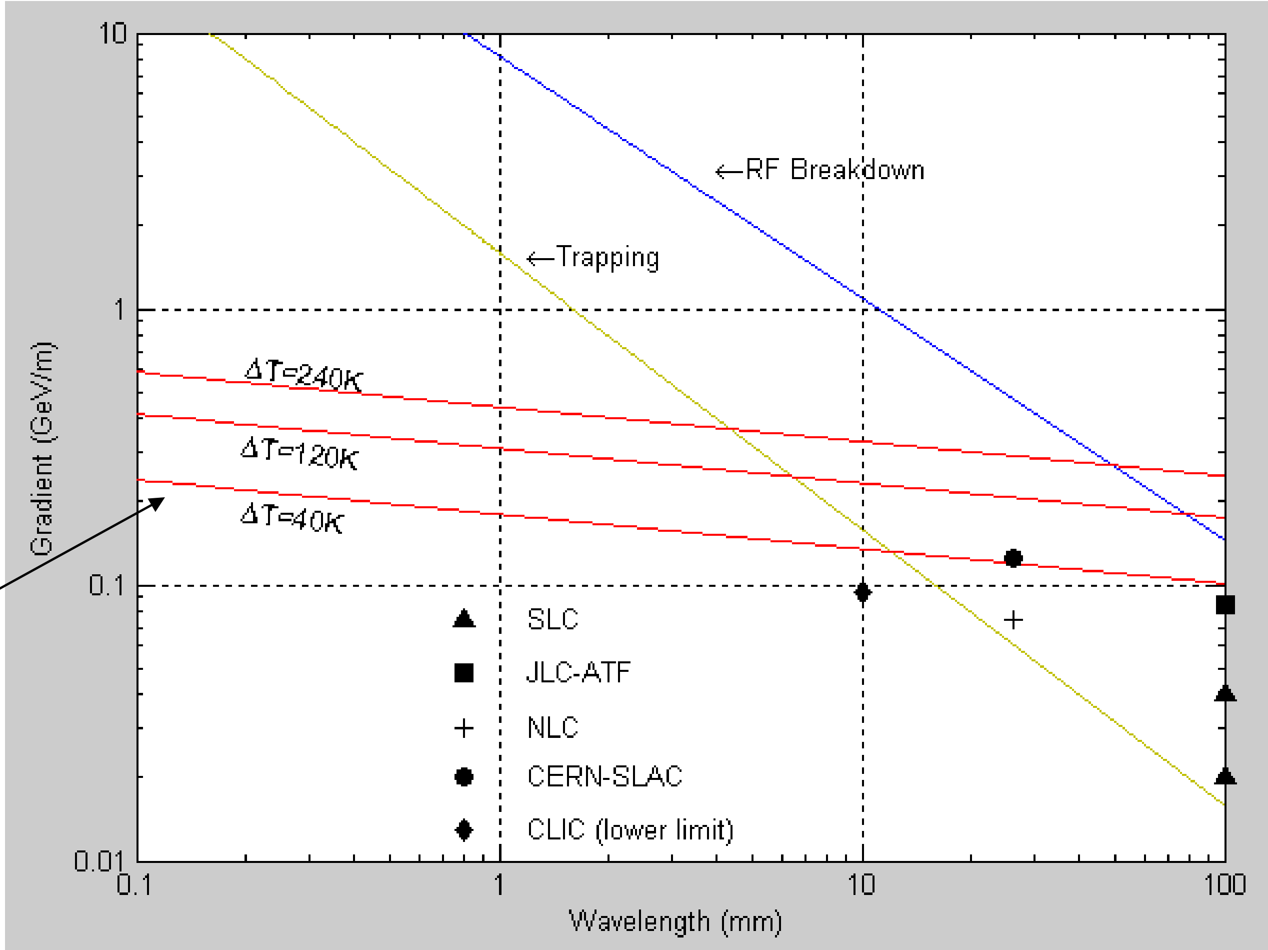
- For the first two years I was working on experiments on the SLC damping rings studying the effects of residual gas on electron orbits
- After I passed my qual, Bob informed me he was creating a new research group, ARDB, and that I would be the first “guinea pig” to complete a thesis under the new charter
- However, instead of working on techniques to try to achieve accelerating gradients of 1 GeV/m, we wanted to understand more about what may limit the gradient for RF linear normal-conducting accelerator structures
- First point of study would be RF pulsed heating in which Bob thought it may only be 1 chapter of a bigger thesis
  - That chapter turned out to be about 290 pages
  - After writing three chapters of my thesis, I eventually succumbed to Bob’s infamous red pen

Accelerating Gradient vs. RF Wavelength

Scaled from
NLC numbers

$$G_{pulse} \propto \omega^{1/8}$$

Pulsed Heating

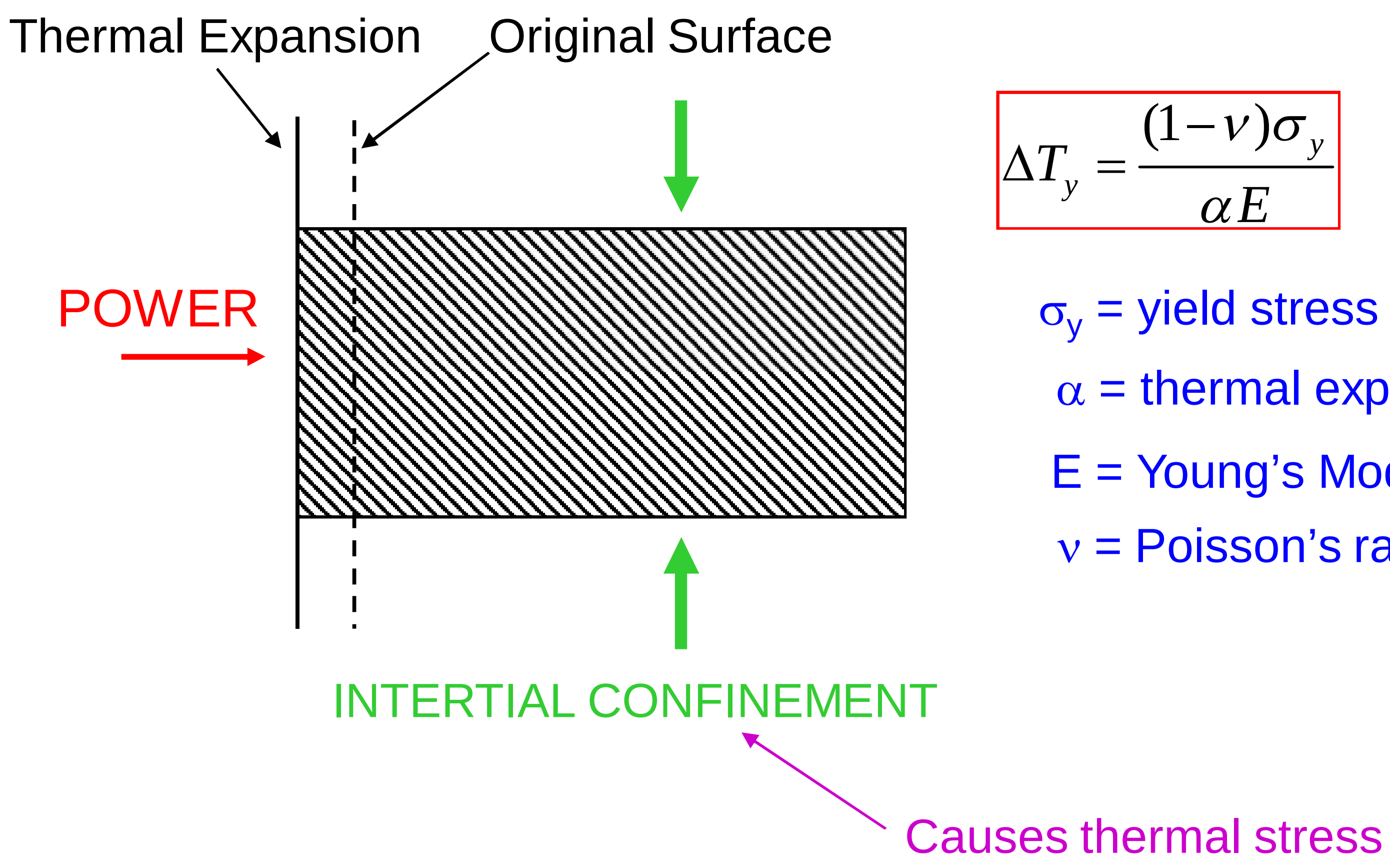


This graph, based on calculations from Perry Wilson in 1996 and Bob Siemann in 1997, was our motivation to study the effect of RF pulsed heating on OFE copper

What Is RF Pulsed Heating?

- Joule heating from pulsed high power RF
- Cyclic stress induced from repetitive heating and cooling of the surface
- Induced stress may exceed yield strength of the metal
- May lead to fatigue of metal surface causing RF performance degradation
- Damage accumulates slowly over time and is not necessarily catastrophic or initially obvious like RF breakdown
- Pulsed heating is more of a “reliability” problem as it can shorten the lifespan of an accelerator structure
- For Oxygen-Free Electronic (OFE) Copper: Simple calculation of Threshold $\Delta T = 40C$

Thermal Fatigue From Pulsed Heating



$$\Delta T_y = \frac{(1-\nu)\sigma_y}{\alpha E}$$

σ_y = yield stress

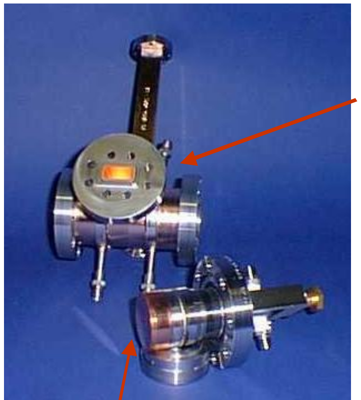
α = thermal expansion coefficient

E = Young’s Modulus

ν = Poisson’s ratio

If $\Delta T_{max} > 2\Delta T_y$ then continuous permanent damage occurs (~ 40C)

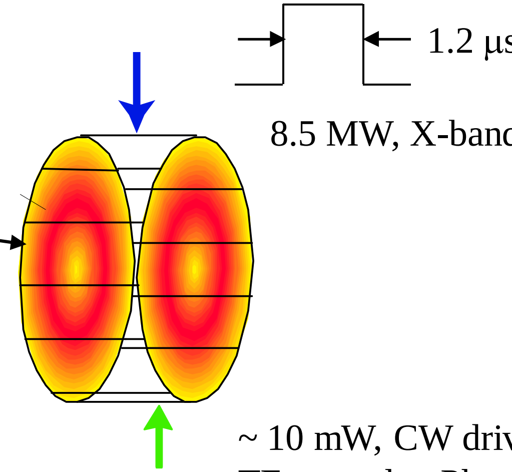
RF PULSED HEATING EXPERIMENT OVERVIEW



TE_{011} Test Cavity

11.424 GHz

Copper test surface



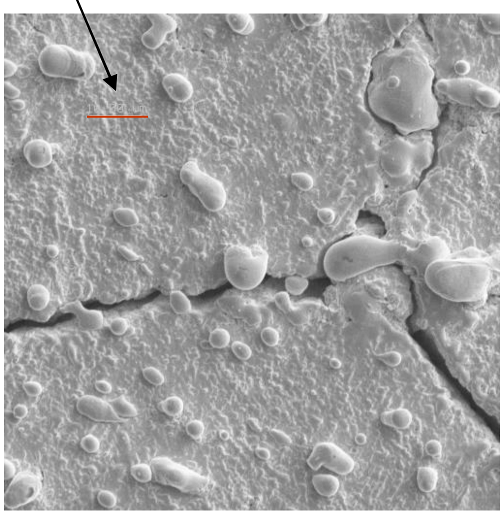
8.5 MW, X-band Pulse

ΔT ~ 120 K

~ 10 mW, CW driving the TE_{012} mode. Phase and amplitude changes during X-band pulse measures ΔT

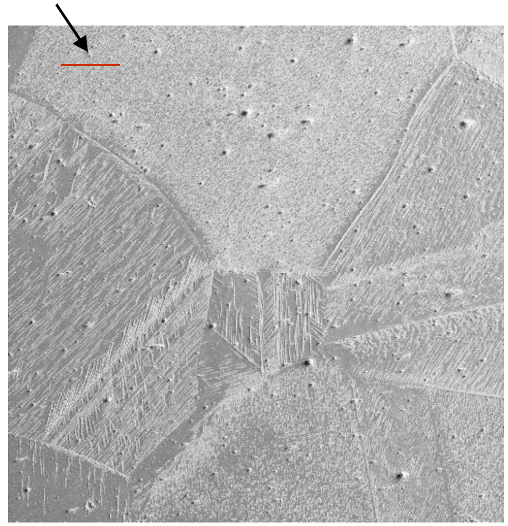
ΔT ~ 120 K
for 56 x 10^6 pulses

10 μm



ΔT ~ 80 K
for 86 x 10^6 pulses

100 μm



ΔT ~ 120K:
Numerous cracks

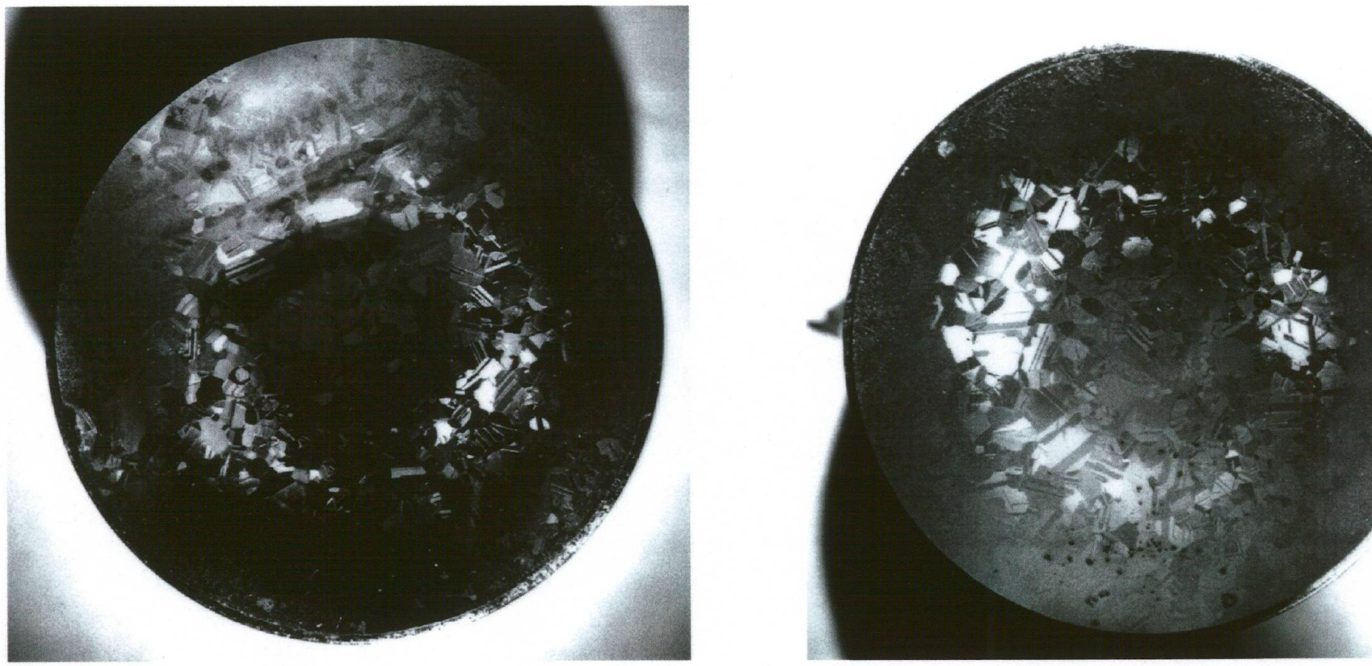
ΔT ~ 80K:
Some cracks
Numerous Slip Bands
Electrical Resistivity increased 25 to 50%

Endcaps From an Experiment Run

After 86 million pulses (or 33 days of run-time at 30 pulses per second)

THICKNESS OF
DAMAGE REGION 6 MM

65 K < ΔT < 82 K

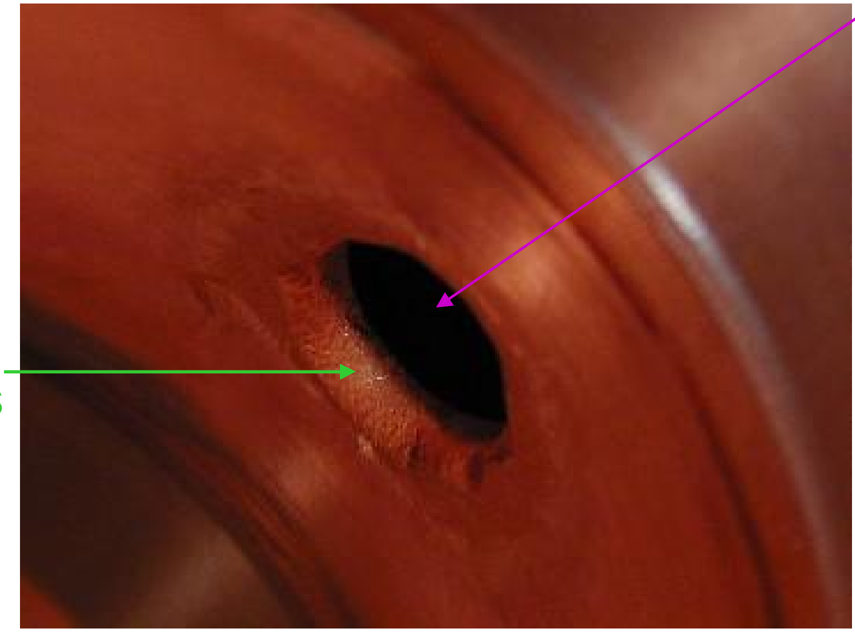


Estimation of threshold ΔT ~ 40K may be correct

Damage of Coupling Aperture

Aperture couples energy from klystron into RF cavity

Aperture rounded in direction of magnetic field where the field is largest



ΔT estimated at 250C

This prevented us from achieving higher power and higher ΔT on the endcaps

I later heard that the NLCTA used these results to redesign their input couplers to reduce the magnetic field near the apertures and achieve higher power

Personal Reminiscences of Bob Siemann

- Despite Bob's incredibly busy schedule, his door was always open and he always made time for me over the years, whether I had an issue, ran into a roadblock, or just wanted to show him something cool
- Bob's attention to detail, his quick insight, and his multitude of ways of looking at a problem, both experimentally and theoretically, along with his infectious enthusiasm helped me to grow tremendously as a scientist and engineer
- As I evaluate my work over time, I find myself often thinking how Bob would perceive it, for he has become my yardstick for which I measure myself
- I do not believe I could have found a better mentor than Bob and I am grateful for the time he has shared with me as his student