RF BACKGROUND STUDIES AND PLANS

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IIT: N. Solomey, Y. Torun
U. Illinois: L. Ducas
Imperial College: E. McKigney
Many others have helped
Introduction

We need to characterize radiation field around RF cavities to

- identify relevant diagnostics for cavity operation
- test and select instrumentation for cooling channel
- understand background environment for detectors in a cooling experiment (MICE)
Problem

- Electrons stripped from metal surface
- accelerated by cavity field, generate x-rays
- dark current absorbed by liquid hydrogen
- x-rays flood downstream detectors
Issues

Initial concern due to results from 805MHz open-iris cavity at highest gradients

- Absorber heat load
  - saw $\sim 1\mu A$ average dark current at 16MV/m
  - deposited energy per particle comparable to muons
  - Study II muon current $\sim 5\mu A$

- Window integrity
  - dark current focused around magnetic field lines
  - burned hole in vacuum window during operation

- MICE detector backgrounds
Field emission

Fowler-Nordheim current density $j_{FN}$ from tunneling through potential barrier (work function $\phi$) at metal surface

$$j_{FN}(E) = \frac{A}{\phi} (\beta E)^2 \exp\left(-\frac{B\phi^{3/2}}{\beta E}\right)$$

$$n = \frac{E}{j} \frac{dj}{dE} \simeq 2 + \frac{67.4 \text{GV/m}}{\beta E}$$
Field emission

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$$n = \frac{E}{j} \frac{dj}{dE} \simeq 2 + \frac{67.4 \text{GV/m}}{\beta E}$$

Data

Emitters

Accelerating Field in Cavity

Local Field at Emitter

Y. Torun – RF Backgrounds – MUTAC – 1/13/03 – p.6/2
Instrumentation challenge

- Extremely steep dependence of $I$ on $E$ ($n \sim 10$ for 8GV/m surface field)
- No single detector/technology can cover (or survive!) entire dynamic range (over 10 orders of magnitude)
- Hard to control systematics and make repeatable measurements
- Had to try (and occasionally fry) many different detectors
- Need to crosscheck results often
Facility: Lab-G
Detectors

- Signals change scale during conditioning
- Dose monitors to track overall progress
- Glass, polaroid/standard film for spatial detail
- Current transformers for dark current
- Scintillators for rates and fast diagnostics
- Ge diode and rangestack for spectrometry
Results
Scintillator+PMT

Fast enough to follow cavity pulse by pulse
Scintillator+PMT

Fast enough to follow cavity pulse by pulse
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Fast enough to follow cavity pulse by pulse
Scintillator+PMT

Fast enough to follow cavity pulse by pulse

[Graph showing PMT pulses, Gate, and RF signals over time]
Scintillator+PMT

Fast enough to follow cavity pulse by pulse

- PMT pulses
- Gate
- RF

805MHz pillbox
TiN–coated Be window
Processing (4–7MV/m)
Jan. 3–7, 2003
Scintillator+PMT

Fast enough to follow cavity pulse by pulse
Scintillator+PMT

Fast enough to follow cavity pulse by pulse

![Graphs showing PMT pulses, Gate, RF, and RF pulses over time.](image-url)
Fast enough to follow cavity pulse by pulse
Scintillator+PMT

Fast enough to follow cavity pulse by pulse

![Graphs showing voltage over time for PMT pulses, Gate, RF, and RF pulses with Tektronix 805MHz pillbox and TiN-coated Be window processing.]
Scintillating fibers

MUSCAT prototype tested Nov 01 (E. McKigney, P. Gruber). New detector (A. Bross) used for MICE background estimates

- Would overwhelm MICE fiber tracker without shielding
- OK with absorber
  - $\sim 1\text{kHz/fiber at }8\text{MV/m} \Rightarrow <10\text{MHz at }200\text{MHz}$
- Improved with conditioning
Glass plate photography

- Put thin plates flush against window (J. Norem)
- Beamlets from single emitters in magnetic field
- Turned into rings at low field
- Radius consistent with ExB drift $r \sim \frac{E}{B^2}$
Photographic paper

- Use Polaroid for short exposures to follow progress in cavity conditioning
- Exposed standard b&w paper, develop, scan (P. Gruber)
- Intensity pattern over large area
- Rangestack with 1.6mm Al plates at 10MV/m →
  - Front layer saturated
  - Can see emitters after 1 plate
  - 2 plates stop dark current
  - uniform x-ray image
Photographic paper

Individual emitters visible

Can follow transport in fringe field

Away from cavity →
Data acquisition

- Existing DAQ system saves slow signals
- Built auxiliary DAQ to make it easier to set up and automate new measurements
- System in use but not integrated yet
### Open-iris vs pillbox data

<table>
<thead>
<tr>
<th></th>
<th>Open-cell</th>
<th>Pillbox</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dark current</td>
<td>25 mA at 16 MV/m, 600 mA at 24 MV/m</td>
<td>Not measurable (&lt;0.1mA)</td>
</tr>
<tr>
<td>Fiber saturation</td>
<td>1.5MV/m</td>
<td>&gt;13MV/m</td>
</tr>
<tr>
<td>at B = 2.5T</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Window interior</td>
<td>covered with Cu</td>
<td>no deposits</td>
</tr>
<tr>
<td>Window failures</td>
<td>two during magnetic field operation</td>
<td>none</td>
</tr>
<tr>
<td>Cavity interior</td>
<td>heavy pitting on irises</td>
<td>some pitting on endplates</td>
</tr>
</tbody>
</table>
All-copper breakdown model

- Observation (J. Norem): stress \((T = 0.5\epsilon_0 E^2)\) can exceed Cu tensile strength at emitter tips
- Deforming surface into sharper features, removing chunks
- Triggering breakdown
- Molten Cu splashes form more emitters
Conclusions

- Pillbox cavity operation shows
  - Absorber heat load not significant
  - Windows can survive dark current
  - MICE detectors can live with projected rates if placed behind hydrogen (at high channel count/cost)

- Surface treatment important for cooling channel

- Need 201MHz prototype for reliable results
Current status

- Identified useful detectors and measurements
- Physical picture consistent with existing data, refining measurements
- Open-cell cavity results submitted to Phys Rev STAB (first systematic study of high-gradient Cu rf in B)
- Successful pilbox cavity run with Cu windows, encouraging results
- Pillbox being conditioned with Be window, studies in progress
Future plans

- 805 MHz testing with Be windows and grids
- Analysis of windows removed from pillbox
- DAQ integration/commissioning
- Improved understanding of emission phenomena, surface treatment tests
- Simulation of electron transport in channel
- Study effect of field configuration (gradient mode)
- More rate measurements for MICE
- Test 201MHz prototype when available