Technology Challenges for DC Guns as ERL Sources

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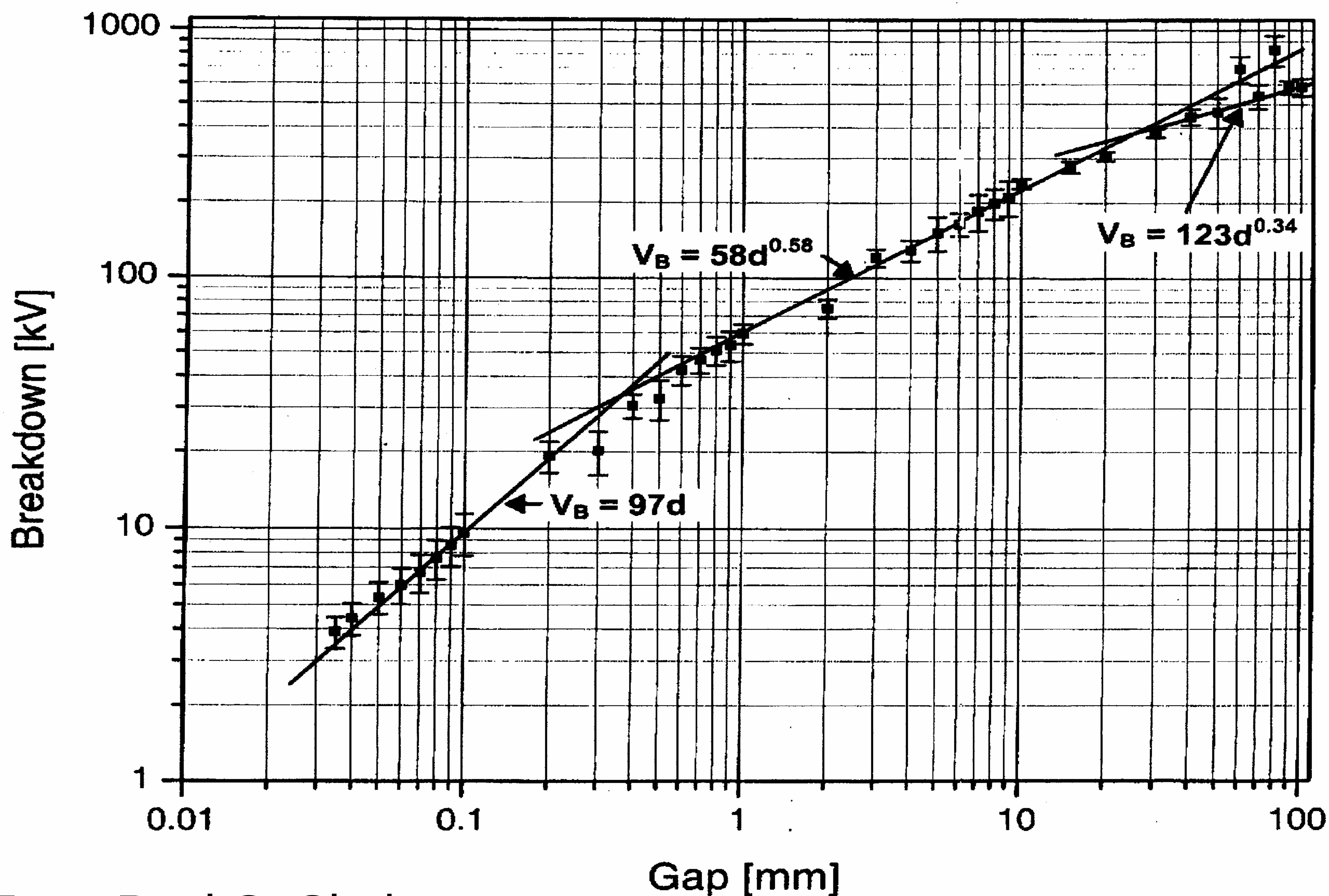
A Bit of History

- DC guns with NEA photocathodes, operating between ~ 70 kV and 350 kV, have been used on many research electron accelerators since 1977
- Early sources delivered a few 10s of μA average current, and a few Coulombs total charge, from a single cathode activation
- Current generation NEA cathodes deliver ~ 10 mA average current, hundreds of Coulombs per illuminated spot, and several useful spots, from a single cathode activation
- We started with Coulombs, we are approaching Ampere-hours, and we need to reach Faradays for a practical NEA cathode delivering 100 mA average current from a very HV DC gun.

The Major Challenges

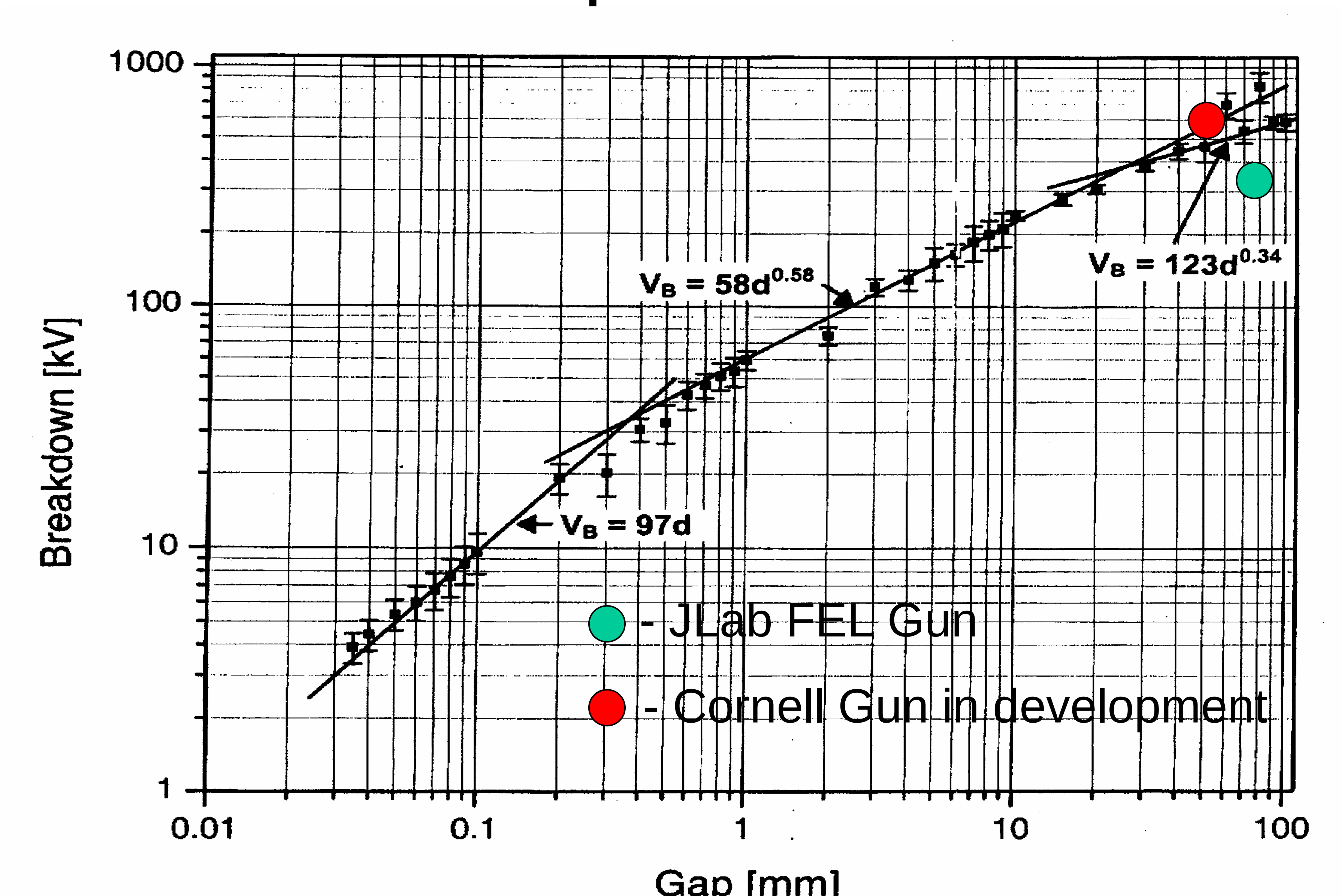
- There is essentially no experience operating photoemission guns at very high voltages (500-750 kV)
- Field emission from electrode structures can lead to voltage breakdown, insulator punch-through, and other less serious problems
- Good operational lifetime for high quantum efficiency photocathodes requires exceptional vacuum conditions – presently at or near the limits of vacuum technology
- Lasers supporting 100 mA operation are presently very much state-of-the-art systems

Vacuum Gap State of the Art



From Paul G. Slade

Vacuum Gap State of the Art



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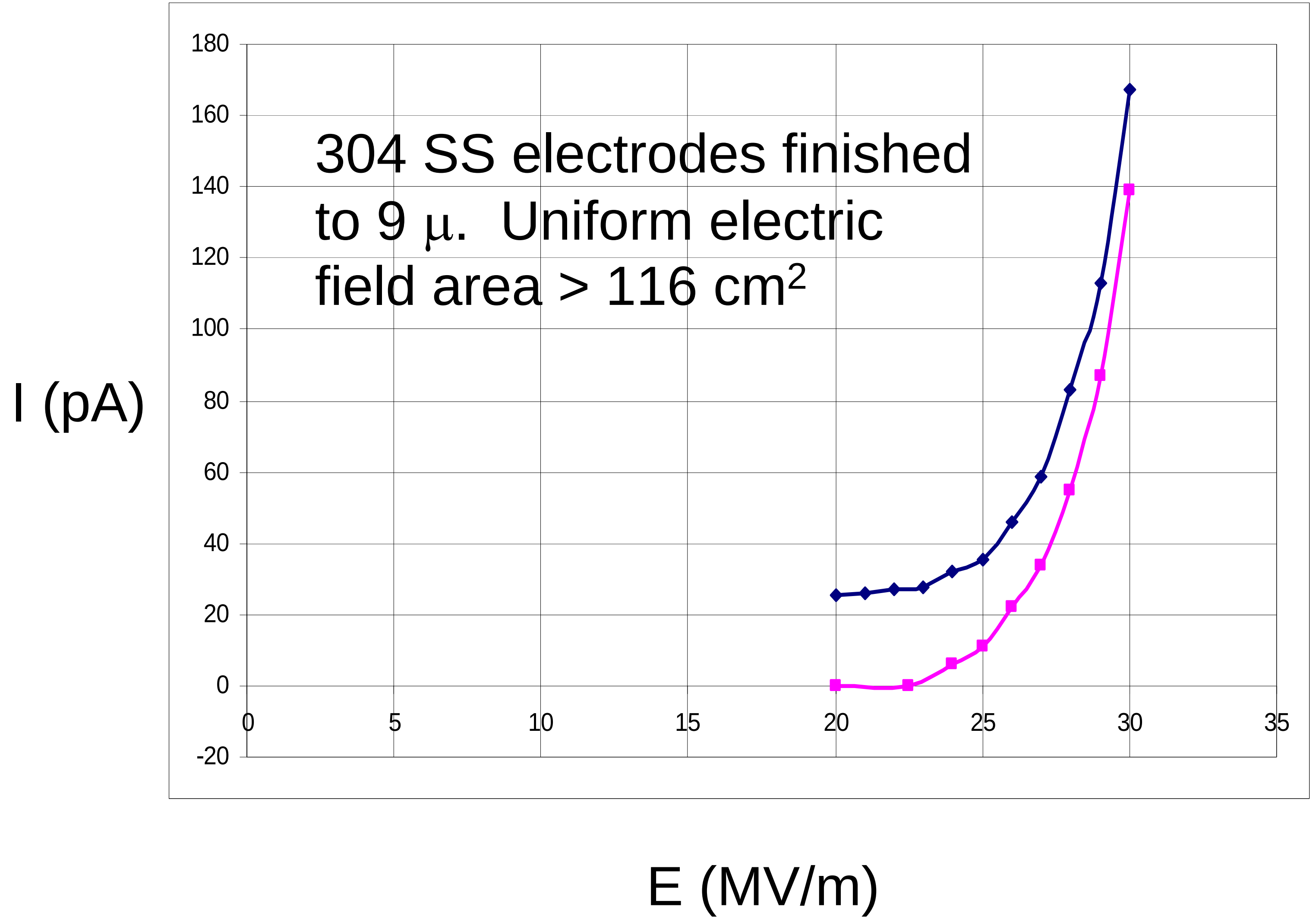
Vacuum Gap Issues

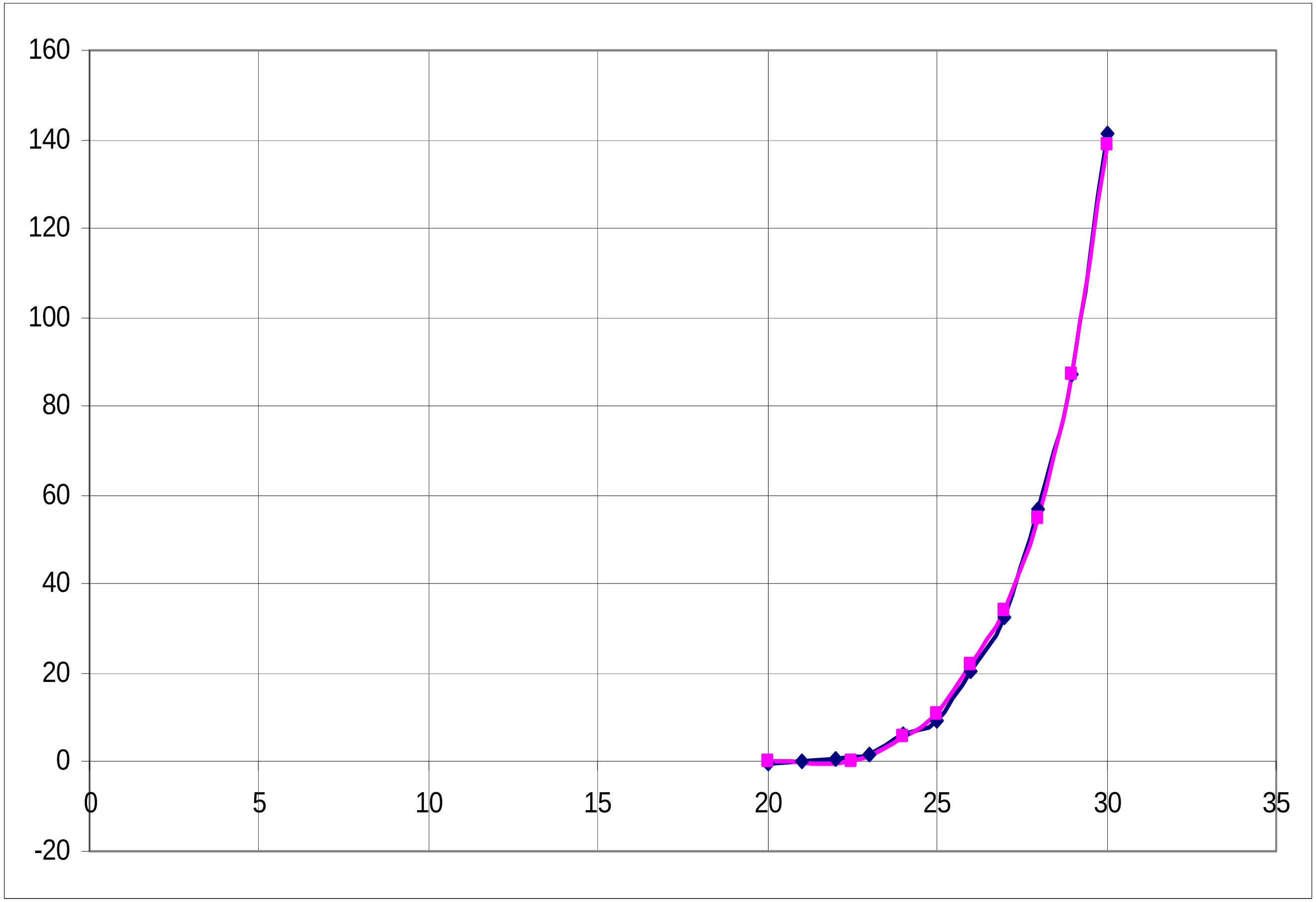
- Criteria for the ideal material properties for the cathode and anode electrodes are not well understood
- Electrode surface smoothness and hardness are important, but not quantified. Surface finishing is presently a very labor intensive step
- Field emission can be greatly inhibited by suitable dielectric coatings
- Coatings to improve anode performance are not presently known
- Coating real electrode shapes, and coating adhesion, are key issues

SiO_xN_y Coated SS Electrodes



SiO_xN_y Coated SS Electrodes

I (pA)

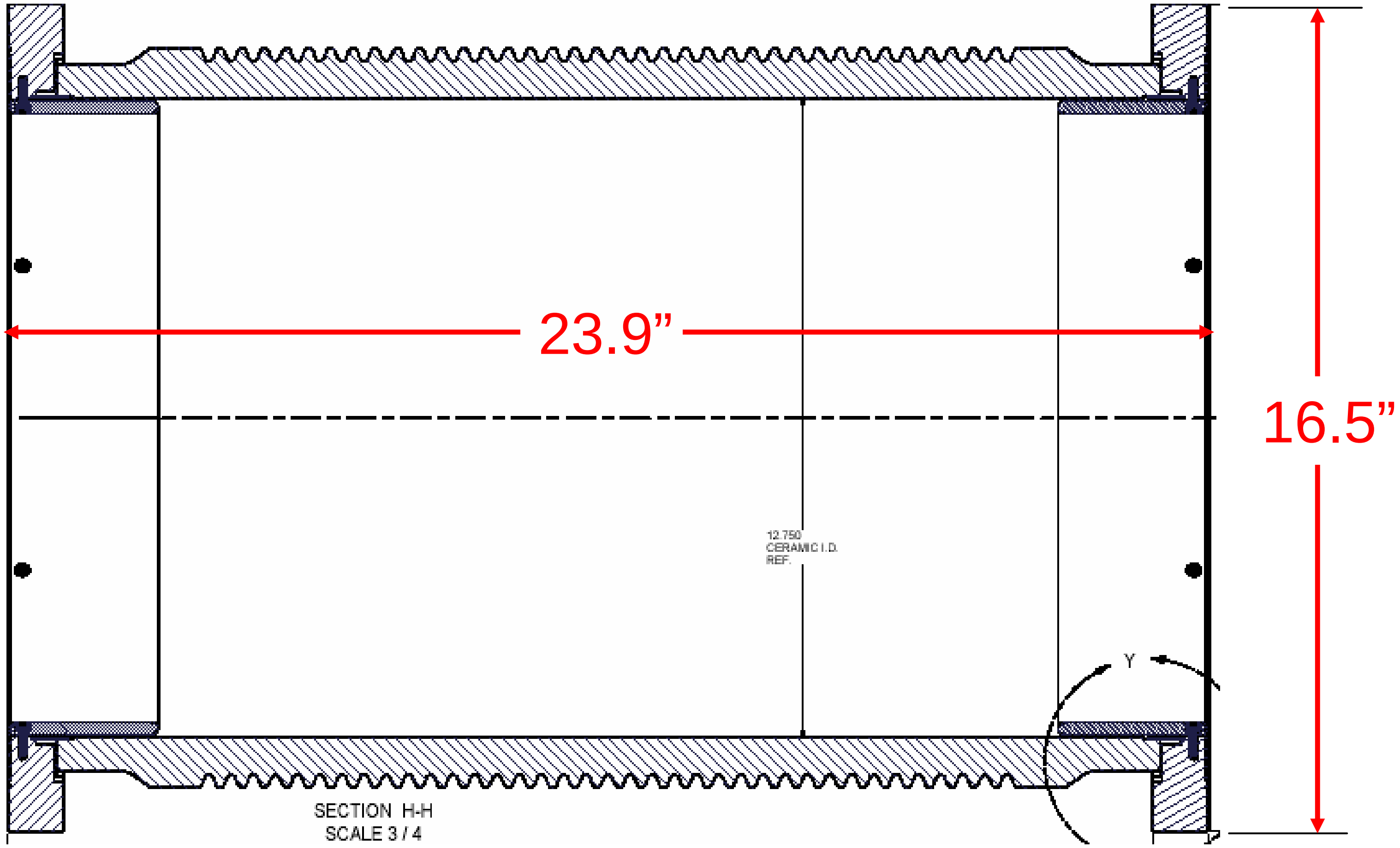


E (MV/m)

Ceramic Insulator Issues

- Field emission from cathode electrode structures can cause charging of the ceramic insulator, and ultimately lead to punch-through failures
- To prevent ceramic charging, one needs a ceramic with a bulk resistivity, or a sheet resistivity on the inner surface. These are NOT easy (or inexpensive) to produce.
- Ion implantation and fired coatings can produce suitable inner surface sheet resistances
- Ceramics with appropriate bulk resistivities are in principle possible, though producing large size ceramics and ceramic-to-metal joints with these materials is problematic

CPI has developed a fired coating with suitable sheet resistance



Cornell 500 – 750 Gun Ceramic 22” long, 12.75” i.d.

Sheet resistivity ~ 7 x 10^{10} Ohms/square

NEA Photocathodes

- NEA photocathodes are NOT harmed by good quality static UHV environments, by illumination with laser light, or by high static electric fields
- NEA photocathodes do not desorb Cs (and thus to not contaminate gun surfaces), and Cs does not migrate significantly on the cathode surface
- Nothing in the process of emitting a photoelectron degrades the photocathode
- NEA cathodes are harmed almost exclusively by chemically active residual gases, or ion back bombardment.

NEA cathode problems solved

- In the JLab polarized electron guns, the cathode 1/e lifetime in the static gun vacuum (produced by NEG and sputter-ion pumps) is > 22,000 hours. The pressure in these guns is difficult to measure, but is likely in the high 10^{-12} to low 10^{-11} mbar range.
- Electrons were demonstrated to originate from non-illuminated, large radius regions of the photocathode. These electrons followed extreme trajectories and struck the walls, releasing gas. They were eliminated by deadening the quantum efficiency at large radius, dramatically improving the photocathode operating lifetime.

Ion back bombardment

- Ion back bombardment creates a track of Q.E. degradation between the illuminated spot on the cathode and the cathode electrostatic center. The 1/e lifetime from this effect is characterized by the coulombs delivered per unit illuminated area. This is an imperfect measure, since all ions do not strike the illuminated spot. The best values obtained in the JLab polarized guns are above 2×10^5 C/cm^2.
- The ions causing the damage have lower energy near the illuminated spot, and high energy at the electrostatic center.

Ion Back Bombardment Operating Lifetime

If the quantum efficiency decays exponentially with the total charge delivered per unit illuminated area – Q_o, and the maximum laser power available is P_{max}, then a cathode with absolute Q.E. η at wavelength λ can deliver a current i for a time T

$$T = \frac{Q_o A}{i} \ln\left(\frac{1.24 P_{\max} \eta}{\lambda i} \right)$$

With the JLab Q_o, a 10 W green laser should support 100 mA from a 3 mm diameter spot on a 10% Q.E. cathode for ~124 hours. The normalized thermal emittance with a GaAs cathode will be below 5 x 10^{-7} mm-mrad.

Cathodes – NEA or PEA?

- NEA (e.g. GaAs) cathodes offer the possibility of very low thermal emittance.
- NEA cathodes have only a single monolayer of oxidized cesium, which can be easily damaged
- PEA cathodes (e.g. K_2CsSb, Cs_2Te) are stoichiometric compounds, and may have much better ion back bombardment lifetimes. This can be a huge payoff, since the lifetime gain with laser power is only logarithmic, while the gain with Q_o is linear. It is very desirable to measure Q_o for PEA cathodes in a real gun vacuum environment.
- GaAsP offers a larger QE than GaAs, but the gain is only logarithmic

Vacuum issues

- Reducing electric field strengths to moderate values forces the gun vacuum chamber to a large size, leading to a large outgassing load.
- Massive NEG pumping, coupled with a large sputter-ion pump to remove gases unpumped by NEGs, should give ultimate pressures at or below the low 10^{-12} torr range.
- Air bakeout at 400 C appears to be a promising means to dramatically reduce the outgassing rate.
- An alternative treatment may be vacuum firing to ~ 900 C for ~ 30 hours (requires 316 LN flanges)

Laser Choices

- Frequency doubled Yb fiber lasers likely provide the easiest path to a high average power (>20 W) visible source for GaAs, GaAsP, and K_2CsSb cathodes
- Frequency doubled Er fiber lasers may perform well for GaAs cathodes, but have a larger quantum defect than Yb (and thus larger thermal problems)
- Passively mode-locked oscillators with SESAM modulators appear to be a good choice to drive an amplifier. Piezo-controlled cavity length is used to lock to the RF master oscillator. RF gain-switched diodes may be an alternative oscillator.
- 20 – 30 W average power green lasers with rep. rates to ~ 1.5 GHz appear practical today

Optical Pulse Shaping

- The ideal transverse shape may not be a “tophat”, but intermediate between that and a Gaussian (cf. Bazarov, this workshop)
- Transverse shaping may be done with aspheric lenses, but this is difficult in practice. An improved solution may be available from Tropel.
- Longitudinal shaping is more complex, requiring, e.g., dispersion and pixelated phase shifts
- The electron beam brightness improvements from proper laser pulse shaping may be large. This is an effort worth pursuing.

1 Amp average current?

- With green illumination, the required laser power-Q.E. product for 1 Amp is 235 W-%
- At some point, laser heating of the photocathode will become a problem
- With a 30 W laser, and a 20% initial QE, the JLab Q_o would give an operating life of only 10 hours at 1 Amp. Clearly we need a significantly higher Q_o for a practical 1 A source
- The bunch charge must increase over the values for a 100 mA gun. This will degrade the emittance, and produce LOTS of HOM power.

Summary

- The parameters required to operate a 100 mA average current, very high voltage DC gun with an NEA cathode lifetime > 100 hour appear to be within reach, but have yet to be demonstrated.
- NEA cathodes offer the possibility of a very low thermal emittance, which is important over a broad range of bunch charges
- Q_o values for PEA cathodes may be much better than for the NEA case, and should be measured.
- A 1 Ampere average current source with good cathode lifetime will require developments well beyond the present state-of-the-art