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Copper Cathode Pulse Energy Deposition

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Question: What is the peak energy deposition and temperature rise in the copper cathode of the LCLS rf gun which is being developed?

For a laser pulse energy of ΔE= 150 μJ, wavelength λ=266 nm, and uniform spot size r_0= 1 mm (The transverse distribution is uniform with a 1 mm hard edge radius. The rms radius is 0.7 mm. [1]), the peak energy deposition in the copper is $\delta E(J/g)$:

$$\delta E = (1-R)\frac{\Delta E}{\pi r_0^2 \alpha(\lambda)\rho}$$

where R is the reflection coefficient and $\alpha(\lambda)$ is the absorption length (as a function of wavelength) and ρ is the density of copper. It turns out that the absorption length in copper in the near UV is very small. The band gap in copper is around 2.1 eV and in the range of λ=266 nm,

$$\alpha^{-1}(\lambda) = \frac{2nk\omega}{c} = \frac{4\pi nk}{\lambda} \approx \frac{8\pi}{\lambda}$$

for $nk \approx 2$ in this range of λ [2]. Also, $\rho = 8.92\times10^6$ g/m^3 for copper. Plugging in the numbers with R = 30% [3], one finds

$$\delta E = 355 \text{ J/g.}$$

For a heat capacity $c_v(T)$ which varies linearly with T:

$$c_v(T) = a_0 + a_1 T$$

the temperature increase δT due to an energy deposition of δE is

$$\delta T = \frac{a_0}{a_1}([1+\frac{2a_1\delta E}{a_0^2}]^{1/2} - 1).$$

In the case of Cu, $a_0 = 0.375$ J/g-^{0}C and $a_1 = 7.5\times10^{-5}$ J/g-^{0}C^2 [4]. For $\delta E = 355$ J/g, the peak temperature rise is δT:

$$\delta T = 872\,^0C$$

It is worthwhile to note that the melting temperature for copper is T_{melt} = *1083* ^0C and the energy required to melt copper is about $\delta E_{melt} \approx 688$ *J/g*. This value of δE_{melt} assumes an initial sample temperature of 20^0C, a heat of fusion of *209 J/g*, the linear model for $c_v(T)$, and ignores the accompanying rapid pressure increase associated with the rapid energy deposition.

The relatively high value of δT brings to mind the question of what happens to the surface after repeated thermal cycling. Work by Pritzkau and Siemann [5] indicates that temperature cycles of *120* ^0C will ultimately (5.5×10^7 pulses) result in grain segregation and separation at the grain boundaries. These cracks seem to be sources of arcing in high rf fields.

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References:
[1]: J.E. Clendenin, private communication.
[2]: N.F. Mott and H. Jones, **The Theory of the Properties of Metals and Alloys**, Dover, p. 117.
[3]: F.A. Jenkins and H.E. White, **Fundamentals of Optics, 4th ed.**, McGraw-Hill, p 536.
[4]: Z. Tang and K. Anderson, *Shock Waves in P-bar Target*, **FERMILAB-TM-1763**
[5]: D.P. Pritzkau and R.H. Siemann, *Results on an RF Heating Experiments at SLAC*, **SLAC-PUB-8554**