Radiation Production Notes
Note 8

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Control of Energy Deposition over Large Area Samples

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It is now reasonable to assume that electron beams in which the 'critical' Lawson current is exceeded (i.e. $\nu/\gamma > 1$) can be propagated over useful distances, but that the form of the beam or propagation mode will depend critically upon the entrance conditions. If the diode were to produce serious radial collapse which is not cancelled at the centre, producing radial electron energies comparable with axial drift energies, the resultant beam, if it propagates at all, will presumably be in a tightly pinched condition with large primary electron transverse temperatures. While possibly of use in the production of very high deposition energy densities over small target areas with small penetration depths consequent on the high mean angle of electron trajectories at the target, this sort of beam would be very difficult to use in the large target area case. However, given a reasonable initial radius at the window with relatively small deviation from orthogonality of the electron trajectories, the production of a beam with small transverse temperatures and reasonable radius appears to be a sensible proposition.

The main problem hence arises in the diode region where the difficulty of preventing radial collapse of the electron stream becomes a major one at high ν/γ ratios. Our rather limited experience suggests that even with $\nu/\gamma \sim 2$ the last 20% or so of the current in a nominally 100 nsec. pulse flows into a central core with a radius less than one quarter of the nominal cathode emission radius. This percentage is deduced from transmission radiography and hence may be larger if the diode voltage is falling off near the end of the pulse; integrated dose αV^n whereas energy α V, where $n \sim 2$-3 in this region. However, as long as no more than this current fraction flows in the core, blocking out the beam centre is acceptable and readily achieved. There is no reason to suppose that this situation will continue to hold at higher ν/γ ratios, except perhaps for the influence of prepulse; as pointed out in SSWA/DWF/6812/109,[1] the necessarily small diode gaps at high ν/γ will suffer considerably from large prepulse voltages or, at the other extreme, high rates of rise of diode voltage with zero prepulse, except in the case of a very large number of point emitters. In any case, at some level of ν/γ, too large a fraction of the electron current will flow in the pinched mode and alternative schemes become essential.

Any change in the electrode/emission area geometry which lowers the effective value of ν/γ is obviously desirable. Three cases suggest themselves as worthy of attention:

(a) Changing the geometry of the emission area from the usual uniformly filled circular form to reduce magnetic effects, while maintaining a single beam. An annular emitter, for example, should produce an electron stream with an overall convergence which is less than that of the uniformly distributed case. A

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better possibility is a strip emitter of roughly rectangular form with a length l several times its breadth b, where very roughly the magnetic field on an edge electron is lower than that in the cylindrically symmetric case by a factor $\sim \sqrt{\alpha/\pi}$, $\alpha = l/b$, being the aspect ratio of the emission area. Even here the gains to be achieved are not very high; for $\alpha = 10$, for instance, the boundary field is reduced by ~ 2. However, the resultant beam from such a system, if it propagates in a stable manner, possesses the advantage of being compatible with target energy deposition requirements. A further possibility arises with the use of shaped electrodes which introduce a radial electric field in the diode region. The resultant radially outward force opposes the magnetic compression force to produce less beam divergence at a given ν/γ ratio than the plane parallel electrode case.

(b) Dividing the emitting area into a large number of smaller emitters with individual ν/γ ratios of the order of unity.
Here again, prepulse may have a significant effect on the way in which current divides among the emitters but, granted that a reasonably uniform distribution can be achieved, the problem remains of the interaction between individual electron streams. Considered from the point of view of a large number of small emitting areas which together sum to a small fraction of the area defined by the boundaries of the emitting region, the net effect is an overall reduction in current density compared with the complete uniform emitter case for the same diode spacing and voltage. The boundary radius of the emitter has increased several times for the same total current and hence the edge magnetic field is lower, leading to less convergence in the diode region.

(c) The limiting case of (b); i.e. the use of several small emitters each with ν/γ of the order of unity, magnetically isolated from one another. In other words, a multiple diode structure fed from a common generator.
If multiple electron streams are used to produce adequately high overall ν/γ ratios, and the optimism expressed earlier concerning the transport of high ν/γ beams turns out to be ill-founded, then the option to use magnetic isolation in the beam transport region may be taken; i.e. each beam is transported within the confines of its individual conducting drift tube, perhaps in the form of a honeycomb or eggbox structure. The problem is hence transferred from the generation and transport areas to the target region

where, in the general case, a reasonably uniform energy distribution is required. Possibilities here are (i) physical convergence of the individual drift tubes to the point where each beam fills its own tube and the positioning of the target immediately at the end of the drift tube structure; and (ii) the insertion of a short drift region and perhaps scattering foils between transport structure and target, within which magnetic interaction produces a near uniform current distribution without leading to too much overall convergence.

The various possibilities, for the most part speculative, for the generation and transport of these high ν/γ beams which have been put forward are summarised in Table I.

TABLE I