Large Area, Low Voltage X-Ray Source

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1. Abstract

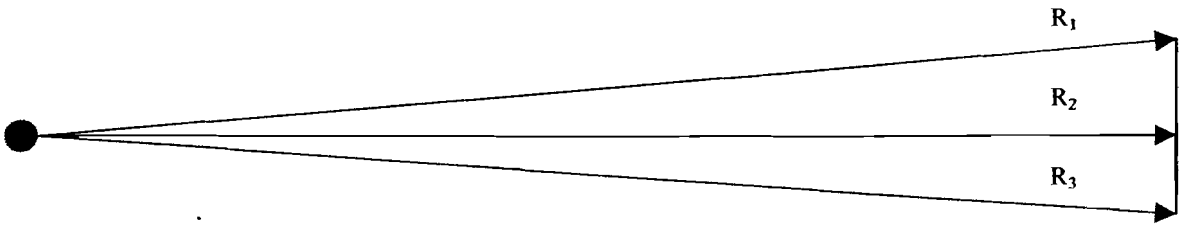
The calibration of various x-ray diagnostics at the Laboratory for Laser Energetics requires a spatially uniform x-ray source, the flat-fielding of an x-ray streak camera providing an example. Uniformity may be achieved with a point source far away or with a large area source nearby. Our source is based on the bombardment of a 1cm by 10cm gold anode with a 3-5 keV electron beam of uniform flux. The beam originates as thermionic emission from a long tungsten filament, and is amplified by secondary electron emission in a discrete dynode chain to the mA level. The spatial non-uniformity of the x-ray source was measured to be +/- 5%. The source may also be gated at 100Hz, useful for measuring geometric distortions in x-ray streak cameras.

2. Introduction

One of the primary diagnostics used in the Laboratory for Laser Energetics inertial confinement fusion (ICF) program is the streak camera. Streak cameras help the ICF program by measuring the detailed pulse shape used in a particular shot, but two key errors limit the accuracy of the recorded images. The first error is a flat field error that exists in any optical system. Flat field errors affect the intensity of a given pixel but not its location. The second error is a geometric distortion that affects pixel location but not its intensity. Both of these imperfections can be corrected by calibrating the cameras with a high spatial uniformity source. Uniformity can be achieved using a point source held at a distance from the detector screen because the large distance reduces non-

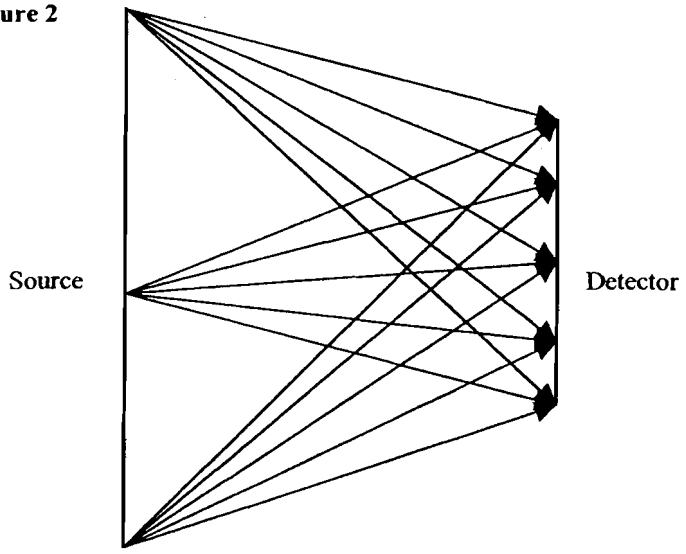
uniformities caused by the $1/R^2$ decrease in irradiance. The problem with this method is that there is low flux reaching the detector plane. Another method of achieving high detector uniformity is to use a high (80-90%) uniformity large area source held at a relatively close distance to the detector. With this type of source the same degree of detector uniformity is achieved, but flux is not sacrificed. This project centered on building such a large area x-ray source for the calibration of x-ray sensitive streak cameras.

Figure 1



From a point source, non-uniformities are introduced because $R_1 \neq R_2 \neq R_3$. There is only a slight gradient in intensity caused by the differences in $1/R_n^2$, for large R.

Figure 2



With a large area source each point on the detector sees the sum of intensities from each point along the source. The detector also sees high flux. Slight non-uniformities in the source are acceptable because of the large number of emitting points along the source surface.

3. Overview

Our source is based on the bombardment of a thin gold anode with a 3-5 keV electron beam of uniform flux. The beam originates as thermionic emission from a Tungsten filament and is amplified to the mA level through a discrete dynode chain. The

dynode chain consists of six amplification stages and ends with the acceleration of the electron beam onto the anode. The anode is a piece of Beryllium foil coated with a thin (500 Å) layer of Gold.

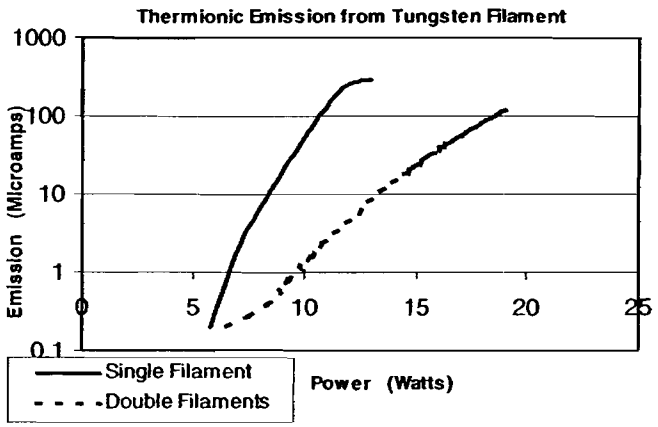
4. Electron beam production

The thermionic emission from the filament as a function of temperature is governed by the Richardson equation[i], shown as equation 1

$$J\ (A/cm^2) = 4\ \pi\ m\ k^2\ e\ /\ h^3\ (1 - r)\ T^2\ \exp\ [-e\phi\ /\ k\ T], \qquad (1)$$

where e is the absolute value of the electronic charge, k is Boltzmann's constant and h is Planck's constant, m is the mass of an electron, $e\phi$ is the work function of Tungsten (4.5eV) and r is a reflection coefficient (0.5 for most metals). As current passes through the filament it heats up and emits the original electron beam. When testing the source a picture was taken of the output x-rays with the current flowing from left to right down the filament, then the direction of current flow was reversed and another picture taken. We observed a noticeable difference between the two pictures, suggesting that there is a thermal gradient along the length of the filament or that the thermionic emission is experiencing ExB drift in the direction of current flow along the filament. To correct this source of non-uniformity we proposed running two filaments, with currents running in opposite directions to average out any thermal gradient or ExB affects seen at the anode. Another advantage of a dual filament system was that the dynode chain has a two-channel design, so each filament could feed one half of the dynode chain. As figure 3 shows, however, in order to get the necessary 10μA of

Figure 3



thermionic emission there must be approximately 13 Watts of electrical power into the dual filaments, compared with 8 Watts for a single filament. Almost all of the power is radiated out according to the Stefan-Boltzmann law[ii], shown in equation 2

$$W = \sigma T^4, \qquad (2)$$

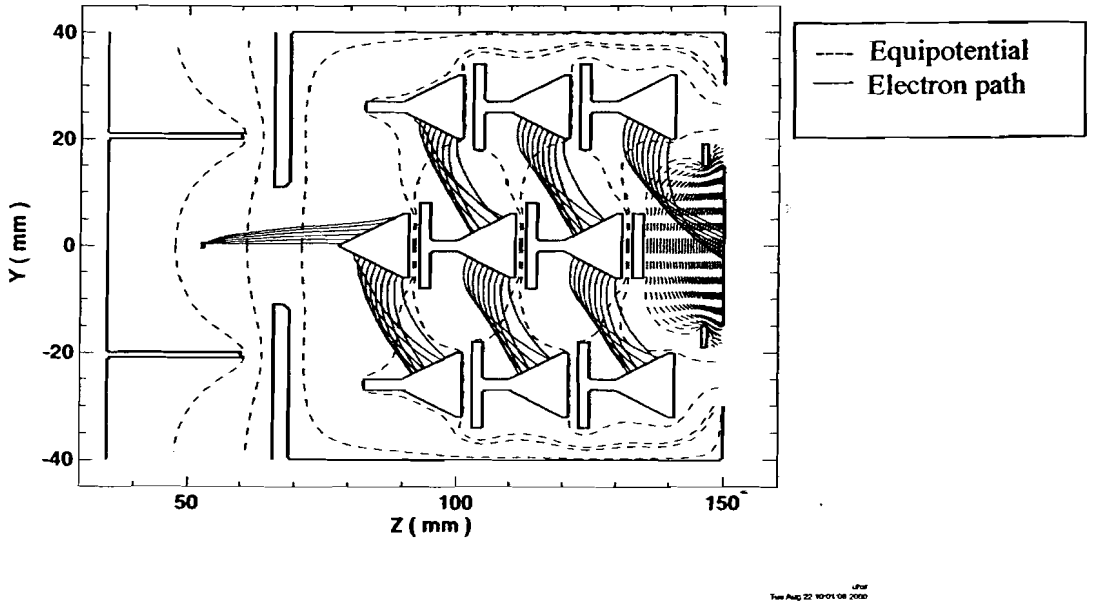
where $\sigma = 5.67 \times 10^{-12}$ W/cm^2 and T is expressed in Kelvin. Thermal loading is currently the main problem with the system, so having the ability to run the filament at a low power is essential.

5. Electron beam amplification

5.1 Dynode geometry

Adequate x-ray flux is produced when the current bombarding the anode is 0.4-3mA, so our original beam current must be amplified. We could run higher power in the filament to achieve our final electron beam current, but as figure 3 shows this would dissipate 15-20 Watts of power into the system, leading to excessive thermal loading. With our discrete dynode chain, we can achieve these current levels with as little as 0.5W of additional power dissipated into the vacuum. Electron multiplication occurs by secondary emission in the dynode chain. The original electron beam is accelerated towards the first dynode, where electrons deposit their energy in the surface layers, knocking out more electrons and producing an amplification of the original beam current. Figure 4 shows the modeled behavior of the dynode geometry used in our source[iii].

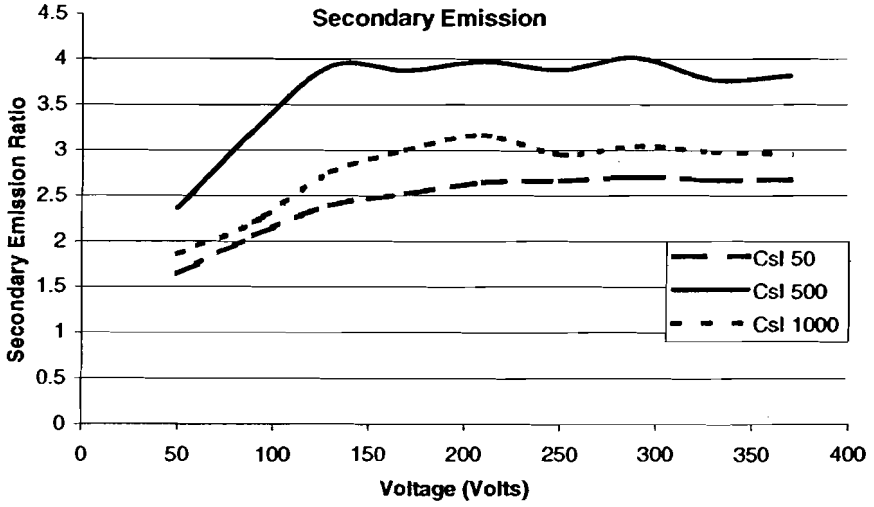
Figure 4



5.2 Coatings

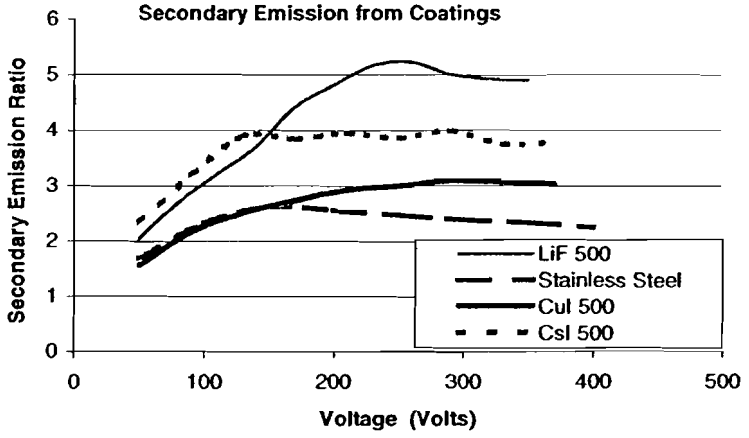
The secondary emission ratio is the average number of secondary electrons emitted for every incident primary electron, and it gives an idea of the total amplification expected for a certain material given a known number of dynode stages. In order to greatly reduce the thermal loading in the system we looked for a material with a large secondary emission ratio to coat the stainless steel dynode structures, thus increasing the amount of amplification throughout the dynode chain and allowing the filament to be run at a lower power. Special consideration was taken with regard to the thickness of each coating. When the electron beam hits each dynode stage it deposits its energy in the first 10-40 Å, so a coating that is too thin will not receive all of the input electrons from the original beam. Figure 5 shows the secondary emission ratio of CsI as a function of the voltage between the filament and dynode 1, for 3 different thickness coatings. The 50 Å coating was too thin to be completely uniform, which may have affected its performance. The 1000 Å coating does not perform well, most likely because of surface charging of the dynode stages, which may affect the extraction efficiency between stages. Optimal coating thickness appears to be 500 Å for all materials tested; at 500 Å thickness uniform coatings can be assured but surface charging is not an observable problem.

Figure 5



The secondary emission ratio of the stainless steel used to build the dynode structure only provides an amplification of 2x per stage, which is not adequate given the number of stages in our source. The ideal coating would have a high (4-6) secondary emission ratio, would be easy to deposit and not be hygroscopic or susceptible to other erosion. The main materials considered were those used for x-ray photocathodes, which operate on the detection of their secondary electron emission, and thus were natural for consideration in our source. Figure 6 shows the secondary emission ratios of four of the materials tested, LiF, CsI, CuI, and stainless steel. LiF was considered because it became apparent during testing that low Z materials were more effective secondary emitters in this system.

Figure 6



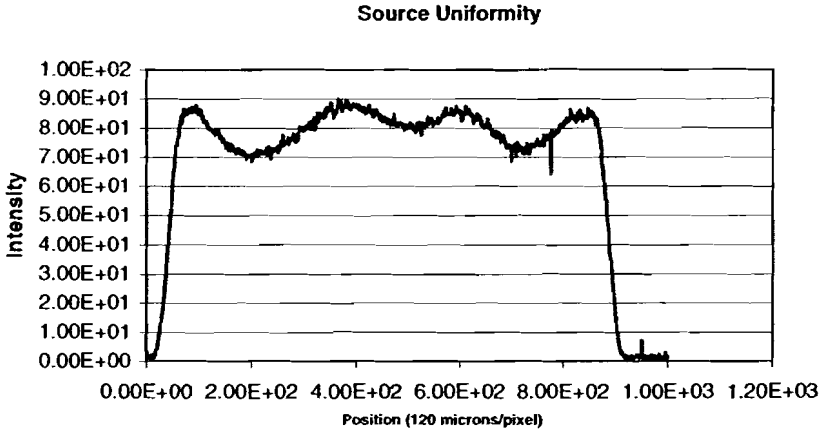
LiF demonstrated emission ratios of over 5, which yields a theoretical amplification of 15,625x, but when implemented the system produced amplification in the 1000-2000x range. This discrepancy can be attributed to slight surface charging, incomplete extraction at each dynode stage, and degradation of coatings over time. There are also some questions regarding the coupling of emission between the first two dynodes, which may be responsible for a reduction of the number of effective stages to 5.

6. Results

After the dynode stages the amplified current is accelerated across 2-5kV onto the anode where it is converted into x-ray emission. A lineout of the x-ray emission along the 10cm dimension is shown in figure 7. It shows the uniformity of the source after

being run for several minutes straight; most of the non-uniformities seen can be attributed to degradation of the thin gold layer.

Figure 7



The imaging system used to take this picture consisted of a pinhole camera that displayed on a phosphor screen deposited on a fiber optic faceplate. A CCD camera was used to record the images from the fiber optic faceplate. All of the pictures taken with the dynode system in place, both with coatings and without, showed sufficient uniformity.

7. Recommendations

The main factor responsible for non-uniformity that we have recognized is the relatively severe deterioration of the gold anode over extended periods of time. One way to reduce this problem is a slight revision in the design, by changing to a thick anode that operates in reflection mode we may be able to correct this problem. Other ways to improve the system include running the source in gated mode and adding more dynode stages to reduce thermal loading. Running in gated mode was observed to increase the secondary emission ratio of coatings because any surface charging would be significantly reduced. Insertion of additional mesh layers to selectively attenuate the electron beam before and after the dynode chain could be used to shape the electron beam and therefore improve x-ray uniformity.

8. References

[i] *Handbook of Physics.* McGraw-Hill Book Company, Inc., 1958.

[ii] *The Photonics Handbook.* Laurin Publishing Co., Inc., 1997.

[iii] Dynode geometry designed and modeled by Dr. Paul Jaanimagi

9. Acknowledgements

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