§24. Simulation of a Novel X-ray Tube

Lee, S.G. (Korean Basic Science Institute, Taejon, Korea),
More, R.

A novel x-ray tube with a line focus was fabricated using a tungsten filament as a cathode in place of the usual coil of tungsten wire. Experimentally, it was found that the electrons emitted from the filament arrive on the anode in a thin line perpendicular to the direction of the filament. The generation of this electron line focus has been studied by a Monte Carlo calculation including electric and magnetic fields in the x-ray tube and Joule heating, surface cooling and electron heat conduction in the filament. The calculations give results in general agreement with the experiments.

The x-ray tube discussed here was fabricated at KBSI in Korea and is intended as an x-ray source for spectrometer calibration. The anode is a 4 cm diameter copper rod and the cathode is a thorium-coated tungsten filament (0.5 mm diameter). The tube voltage is 2-10 kV and the filament current is about 20 amps. The tube produces Cu characteristic X-rays and a bremsstrahlung continuum. The x-ray source region has been determined with movable slits and coincides with the slight discoloration produced by electron heating of the anode surface. This source region is a line (slightly curved) perpendicular to the direction of the cathode filament.

The electric and magnetic fields in the tube are produced by current in the cathode and the strong voltage between cathode and anode (described by a 2-D image potential). Electron motion in these electric and magnetic fields is calculated by numerical solution of Newton's equations. The electrons are launched from the center of the filament by a Monte Carlo algorithm which gives them arbitrary emission location and velocity (consistent with their thermal energies). The trajectories are found to arrive in a thin curved strip on the anode consistent with the experiments.

To understand why electrons are only emitted from the center of the wire, we performed a calculation of heat flow in the wire. This calculation included Joule heating by the current in the wire, electron heat conduction and cooling by thermionic emission (Richardson cooling), and by emission of radiation. The necessary physical data, including temperature-dependent electrical and thermal conductivities, was obtained from various Handbooks. The ends of the wire are thermally clamped by the support structure.

The results of this calculation show that the center of the wire has the highest temperature. In a certain narrow range of parameters, the strong dependence of thermionic emission on temperature leads to a narrow region of electron emission at the center of the wire. This is generally similar to the experimental results.

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