Advances in Cold Cathode Physics and Technology


Invited Paper

We review recent progress in the physics and technology of cold cathode electron emitters. The characteristics of emission from field emitter arrays, photocathodes, and ferroelectrics are presented, together with a summary of the understanding of the physics involved. The paper concludes with a description of L-band micropulse gun, based on secondary emission in an RF cavity. Emphasis is placed on cathode development for electron guns to drive microwave tubes and RF accelerators.

Keywords—Cathodes, electron beams, electron emission, ferroelectric materials, microwave tubes, linear accelerators, photo electricity.

I. INTRODUCTION

In this paper we address the topic of new approaches to the production of high brightness electron beams. For many years, vacuum electronic devices have used thermionic cathodes as the preferred source. Cathode currents of up to several hundred amperes have been produced with durations of a few microseconds, usually at current densities of order 10 A/cm² and repetition rates of about 100 Hz. At these high current levels, substantial beam compression is needed for microwave sources at frequencies in excess of a gigahertz. Cathode lifetimes, in this mode of operation, extend to many years. Similarly, continuous operating microwave devices, which operate at power levels in the Watt to multikilowatt regime, require cathodes with comparable multiyear life. Recent advances have been driven by needs for ultrahigh-power devices with higher available emission current densities, and by the desire to directly modulate the electron beam at the source. In addition, direct modulation of the beam to produce a train of short pulses is of interest for cathode use as a buncher for RF linacs. We shall address both of these topics in the following sections.

In Section II, we review recent developments in field emission and direct modulation of electron beams using field emission arrays (FEA’s). Field-emission cathodes have been fabricated using a variety of materials and by a variety of methods. Single tips with a radius of curvature about 60 nm to 90 nm have been used to generate current densities of more than 10 A/cm², and arrays of tips have generated current densities of 10 to 2400 A/cm², which exceed current densities available from thermionic cathodes. Emission from gated FEA’s can be initiated by the application of gate voltages of less than 100 V. Among the advantages envisioned for FEA’s is the ability to address and control the emission spatially and to directly modulate the emission current. Normalized beam brightness from single tips with total currents of 10 mA is estimated to be on the order of \(10^{15} A/(m^2 \cdot \text{steradian})\), about a factor of a hundred to a thousand times better than thermionic cathodes. Studies are being carried out to measure the beam emittance from these tips. The emittance from an array of tips is, however, poor without integrated lenses on each tip.

Two traveling-wave tubes (TWT’s) have been successfully operated by NEC Corporation using lateral resistor-stabilized FEA’s and arc-resistant FEA’s. The TWT driven by the arc-resistant FEA’s achieved 5000 h of operation. The test was terminated by a cause other than arc failure. Direct modulation of the emitted beam can improve the...