Across-the-target Distribution of Current and Resolving Power of Field-Emission Probing Systems in Terms of Wave Theory

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Rapid advancement of nanotechnology calls for both perfection of instruments currently used in microelectronics and development of new nanometer-resolution tools. Widely used in science and technology, electron and ion probing systems are among such instruments. Their basic parameters – current and resolution – are fully determined by current distribution in the target plane. If we know how to control current density across the target, then we know basic factors that define extreme abilities of this kind of systems.

It is a common opinion that across-the-target distribution of current is a kind of Gaussian function whose variance is dependent on system aberration coefficients. It suggests that the resolution of probing systems is governed by the full width at half maximum, which is assumed to be the mean square of spherical and chromatic aberrations. However, experiments showed that with probing systems using field-emission sources the target-plane distribution of current density differs from the Gaussian curve. For example, in experiments with a liquid-metal ion source [1] the distribution of current density was found to have an unusually long ranging tail – with the overall dispersion radius of 800 nm, half the current concentrated in a 18-nm spot. In the previous paper [2] we dealt with the target-plane distribution of current using the corpuscular method and taking into account spherical and chromatic aberration. Surrounded by extended halo of low current density, a high-current-density caustic was found to form in the target center. The resultant distribution of current density had integrable discontinuities on the axis and border of the caustic, which made it necessary to take into consideration the effect of emission statistics on the target-plane distribution of current.

Now we treat the problem allowing for quasistationary behavior of current-density distribution. It is known [3] that with this approach it is necessary to solve the wave equations to determine probability function correlations in different points of the beam. That is to say, the correlations in the current-density distribution caused by variations in the emission angle of particles will be defined by solving the wave equation, given the interaction between the wave and cutting diaphragm. The paper shows that because of high accelerating fields in the immersion lens of the accelerating electrode, the curvature of the wave front of a point field-emission source in the cutting-diaphragm plane is much smaller than the radius of the diaphragm opening. This allows the conclusion that diffraction has effect only on the outermost rays of the beam if $\frac{r_s}{\rho}\sqrt{\frac{U_p}{kT}} >> 1$ (where r_s - the radius of the diaphragm opening, ρ- is the radius of curvature of the emitter, U_p- is the accelerating voltage and kT is the initial energy of particles). Therefore, the distribution of current density across the target is dependent on interference between sources in the center of the emitter and diffraction of outermost rays. Earlier, wave contribution of electron beams to the distribution of current density across the target was considered in [4]. However, that paper used conventional Kirchhoff-Huygens method for computing diffraction effects in the distribution of current density, which does not let us to allow for spherical and chromatic aberration in full. The smallness of the beam diameter permits use of parabolic approximation [5] in solution of the wave equation, which is similar to use the principal-ray method [6] in corpuscular approximation.

The paper gives across-the-target distribution of current density and frequency-contrast characteristic as quadrature functions of the source-target distance and parameters of the source and focusing system (including spherical and chromatic aberrations). The algorithm that allows computation of these functions is presented. The functions can help construct electron and ion probing systems and correct their aberrations (e. g. in electron-beam imaging or pattern analysis).

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