Thermoelectric effect in field electron emission from nanocarbon

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In the past decade, there has been much interest to the study of field electron emission (FEE) in various carbon nanostructures in the hope to make a field-emission cathode providing electron current densities of about 10^3 Acm^{-2} at electric fields less than 10^4 Vcm^{-1} and operating in relatively low vacuum of 10^{-6} Torr.

However, the fundamental nature of FEE in carbon nanostructures still remains unclear, which hinders from reaching the above mentioned parameters till nowadays and makes the optimal choice of structure for the carbon emitter impossible.

We are suggesting a new approach to the design of field electron emitter based on a theory, which for the first time takes proper account of thermoelectric effect produced by phonon drag effect in nanocarbon structures [1]

According to this approach, the emission is thought to be due to processes occurring in graphite-like (sp^2) region of a few nanometers in size, named as emission center. The center is heated by the ohmic current passing through them. Diamond-like (sp^3) regions represent a kind of coolers removing the heat from the emission centers. As a result, a temperature gradient is established between the emission center and the diamond regions, creating a phonon flux. This induces an inner local electric field at the emission center. The local field, in turn, decreases the effective work function, increasing the emission current.

Basing on this idea we can suggest the optimal structure of an emitting carbon center made up of crystalline diamond (sp3) and a conductive graphite (sp2) regions.

The electron emission current is responsible for the heating of the sp^2-regions in the emission center, while the high thermal conductivity of the sp^3 (diamond)-regions produces the temperature gradient. The diamond grain must have a thermal contact with the massive conductive cathode.

Thus one can consider that FEE occurs in emission center under the influence of inner electric field. Electron emission current results in the heating of the areas of emission center which are facing the vacuum. The existence of the crystalline diamond (sp3) regions results in lower temperatures of the areas of the emission center, which are in contact with sp3 regions. The temperature difference caused by these conditions supports the inner electric field and thus the emission process.

Note that the electron drag effect may be significant only in polycrystalline semimetal and semiconductor films with a small grain size at a large temperature gradient. Such conditions arise in the mixture of diamond-graphite clusters. In metals, this effect is unessential.

An analytic theory based on abovementioned model has been suggested. This theory explains all main experimental features observed in diamond-like films. A microscopic theory of quasiballistic phonon-electron drag effect is proposed. We believe that the good basis for designing a carbon field emitter may be nanodiamond clusters produced by detonation synthesis, which consist of a diamond region of 40 angstroms in size surrounded by a graphite-like shell.

1. A.T.Dideikin, E.D.Eidelman, V.I.Siklitsky, A.Ya.Vul'. The Mechanism of Autoelectron Emission in Carbon Nanostrucrures Solid State Communication, 126, 495 (2003).