분과초청 9

Physics and technology of electrohydrodynamic ion emitters in the Novosibirsk Institute of Nuclear Physics, Russia.

V.G. Dudnikov, A.L. Shabalin*.
Institute of Nuclear Physics, 630090, Novosibirsk, Russia.
*Present address: Kwangwoon university, 139-701, Seoul, Korea.

ABSTRACT

A review of investigation in the physics and technology of electrohydrodynamic (EHD, liquid metal) ion emitters, developed in the Novosibirsk Institute of Nuclear Physics is presented. The EHD emission of high brightness ion beams from melted dielectric is discussed. The dynamics of spontaneous oscillation with a quasi discrete spectrum in the frequency range of up to 100 MHz, transient processes in emission, emission stability at low and high current, physical models for the emission surface size calculation has been studied. The evolution of the momentum distribution function was analyzed. Some examples of the utilization of the designed EHD sources for submicron ion beam production, for micro machining and micro diagnostic, for high voltage accelerators are discussed, too.

EHD ion emitters are very attractive by reason of extremely high brightness and their physics is very interesting too. In the former Soviet Union and in our Institute the EHD investigation was started about 1983. The paper is a review of some our results from 1983 to this time.

The theoretical investigation of emitter zone size based on the Bernulli equation [1] showed that at low emission current the size is constant, $r=r_0$; with the change of the current the emission density changes. At high current the emission density achieves its maximum value $j=j_0$ and with the change of the current the emission zone size changes. Some results for different materials are presented in Table. E_0 is the evaporation field, Vm is maximum velocity of liquid, if $j=j_0$, and I_1 is the critical current value at which the current density achieves saturation. The question does surface tension of liquid metal changes or not in ultimately strong electric field near emission zone was investigated in [2] (the result of [2] : small, 10% decrease of surface tension is possible).

It is known that with a decrease of the voltage, the current of the EHD emitter decreases smoothly to $i=i_{min}$ and then drops sharply to zero. The mechanism of the low current instability was proposed by Kovalenko (Kiev, Ukraine) and Shabalin [3]. The calculated results for i_{min} and experimental data are given in Table. The dependence of i_{min} on temperature is closed to calculated value. However, there are some discrepancies in the absolute value of i_{min} because of some uncertainty in the emission zone shape. In spite of the fact that [4] informed on obtaining nanoampere currents of the EHD emitter, the results of experiments [5] with the high temporal resolution have shown that at average current of EHD emitter $i<i_{min}$ the emission occur by short pulses with pulse current $i=i_{min}$ and the pulse repetition depends on the average emission current i.

The dynamics of EHD emission was studied in [6,7] at various voltage values. With fast applying U to EHD emitter the time prior to emission occurrence t in wide range is determined by the equation

$$t=t_o[(\frac{U}{U_o})^2-1]^{-2},$$

t_o,U_o are constants.

The high frequency instability of EHD emission at large current was discovered first by

Dudnikov and Shabalin [6]. This instability, related to the development of capillary oscillations of Taylor cone, is developing at current higher than some threshold value and leads to the modulation of the emission at frequencies up to 100 MHz. For Ga-emitter the threshold current $i \sim 25 \mu A$. Fig.1 shows the dependence of current noise intensity [8].The generation of the charged clusters at large current was explained in [8] by droplets break off at the intense oscillations of Taylor cone.

The EHD emission of ions from the melts of nonmetallic materials like $LiBO_3$, NaOH was obtained first in [9]. On the technological features of obtaining ions of various elements (P^+, B^+, ,Sb^+, Si^+, Al^+) was informed in [8,10] (Fig. 2).

The energy spread and virtual source size of EHD - emitted ions were calculated in [11]. The calculated value for virtual source size of EHD emitter $a \sim 30$ nm [11] is in a good agreement with the experimental result $a = 40 \pm 20$ nm [12]. More detailed calculations of virtual source size and current density distribution at the periphery of submicron probes were performed in [13,14] not only for EHD but also for field electron emitters and for the gaseous field ion sources too.

First simple ion-optical systems with EHD-sources for technological applications and ion micromachining experiments was developed in our Institute in 1986 [15]. More complicated microbeam system was developed later, and some technological experiments were perform too [16] (Fig.3,4).

A new result was developing of high intensity ion optical system with EHD-source as an injector for high voltage electrostatic accelerator [17]. In the continuous regime the ion beam of Ga^+ and In^+ with current 0.1 mA and energy 1.1 MeV was obtained.

REFERENCES

1. A.L.Shabalin, Dokl.AN SSSR v303, 357 (1988).
2. A.L.Shabalin, J.of Appl.Mechanics and Technical Physics v33, 12 (1992).
3. V.P.Kovalenko and A.L.Shabalin, Pis'ma Zh.Tekn.Fiz. v15, N6, 62 (1989).
4. A.E.Bell, S.Rao, G.A.Schwind, and L.W.Swanson, J.Vac.Sci.Technol. B6, 927 (1988).
5. A.L.Shabalin, Pis'ma Zh. Tekn. Fiz. v15, N23, 27 (1989).
6. V.G.Dudnikov, A.L.Shabalin, Soviet Physics-Technical Physics v30, 462 (1985).
7. V.G.Dudnikov, A.L.Shabalin, Soviet Physics-Technical Physics v32, 112 (1987).
8. A.L.Shabalin, Candidate's thesis, Novosibirsk, 1989.
9. V.G.Dudnikov, A.L.Shabalin, Sov.Tech.Phys.Lett. v11, 335 (1985).
10. V.G.Dudnikov, A.L.Shabalin, Sov.Tech.Phys.Lett. v11, 490 (1985).
11. V.G.Dudnikov, A.L.Shabalin, Soviet Physics - Technical Physics v35, 479 (1990).
12. M.Kamura, T.Kanayama, H.Hiroshima, and H.Tanoue, Appl.Phys.Lett. v42, 908 (1983).
13. A.L.Shabalin, J.of Appl.Mechanics and Technical Physics v33,141 (1992).
14. A.L.Shabalin, J.of Appl.Mechanics and Technical Physics v33,769 (1992).
15. V.G.Dudnikov, A.L.Shabalin, Instruments and Experimental Techniques v29, 1148 (1986).
16. A.N.Dubrovin, V.G.Dudnikov, D.V.Kovalevsky, and A.L.Shabalin, Instruments and Experimental Technique v34(2), 430 (1991).
17. M.E.Veis, V.G.Dudnikov, R.A.Salimov, V.G.Cherepkov, and A.L.Shabalin, Instruments and Experimental Techniques v32(2), 294 (1989).

Element	Eo (10^8V/cm)	r_0(Å)	Vm (m/s)	j_0 (10^8A/cm^2)	I_1 μA	Temperature	i_{min}(μA) calculations	i_{min}(μA) experimental
Al	1.8	13	1100	9.4	100	800℃	1.5	1.4
Ga	1.6	12	610	5.1	46	30℃	0.47	0.28
Ga						800℃	1.0	0.7
In	1.3	15	450	2.7	38	330℃	0.44	~0.5
Cs	0.4	17	280	0.36	6.5	30℃	0.08	~0.1

Fig.1 The dependence of current noise intensity (f=10 kHz) on the emission current. Circles are experimental results, the dotted line represents shot noise.

Fig.2 Mass spectra of the ion beams from the EHD emitters with various working media. a) Copper - phosphorus alloy; b) the alloy $Ni_{45}B_{45}Si_{10}$; c) aluminum.

Fig.3 Ion - optical column: 1) source - movement mechanism; 2) ion source; 3) ceramic rods; 4) electrodes of einzel lens; 5) flanges; 6) defector rods; 7) secondary electron detector; 8) movable stage; 9) aperture diaphragm; 10) tip of ion source.

Fig.4 Inscription made by ion beam. The height of the upper - case letters is 6μm.

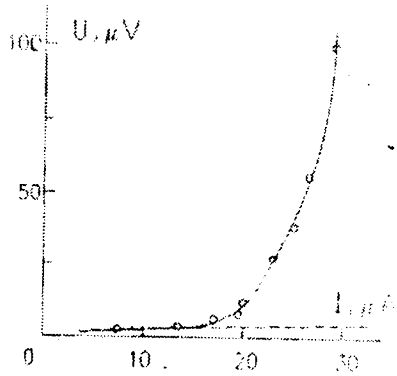

Fig. 1

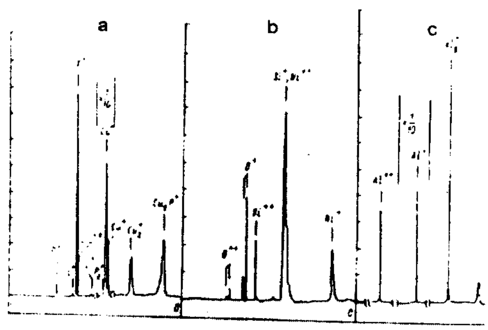

Fig. 2

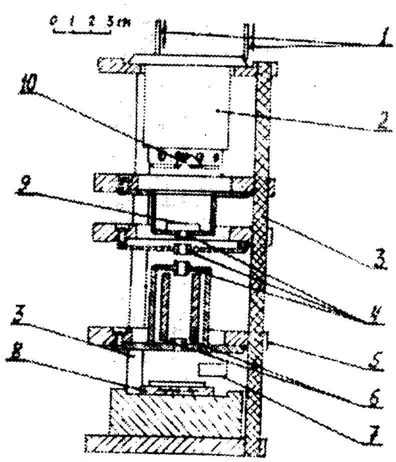

Fig. 3

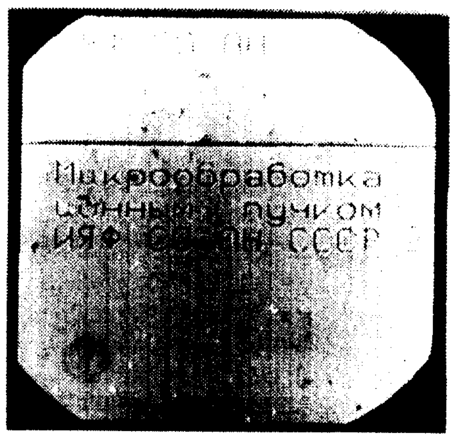

Fig. 4