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INVESTIGATION OF A LIQUID Ga ION SOURCE AT LOW EMISSION CURRENTS

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RESUME

Nous présentons des mesures de la distribution d'énergie et de l'intensité angulaire d'une source d'ions à gallium liquide qui indiquent la possibilité de réduire la largeur à mi-hauteur de la distribution d'énergie en utilisant des pointes fines avec un apport réduit du metal liquide. En même temps nous trouvons une perte d'intensité angulaire. Ensuite quatre différentes tetrodes sont comparées.

ABSTRACT

Measurements of energy spread and angular intensity of ions emitted from a liquid gallium ion source are presented which indicate that it is possible to reduce the energy spread without losing much of the angular intensity by using sharp emitters with a higher flow impedance. Furthermore different tetrode lens systems are compared for their suitability with such sources.

Introduction

The performance of ion microprobe instruments using liquid metal field emission sources is usually limited by lens aberrations of the probe-forming optical system. We shall treat a liquid gallium ion source consisting of the field emitter and a tetrode system which is often responsible for most of the lens aberrations.

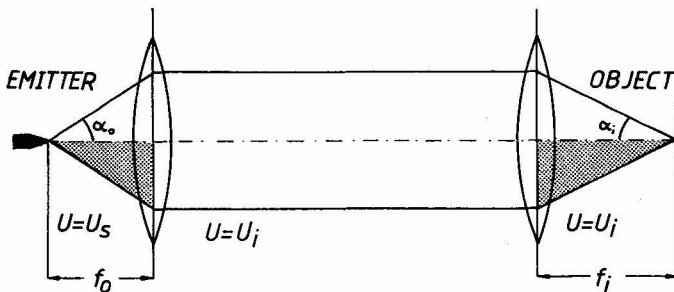


Fig 1. Schematic drawing of the probe - forming system

The contribution of the extraction optics to the diameters d_s and d_c of the spherical and chromatic disc of confusion at the position of the object is given by

$$d_s = MC_s \alpha_o^3 = C_s \left(\frac{I_p}{\pi \left(\frac{dI}{d\Omega} \right)} \right)^{\frac{3}{2}} * \frac{f_i}{f_o} * \left(\frac{U_s}{U_i} \right)^{\frac{1}{2}}$$

$$d_c = MC_c \alpha_o * \frac{\Delta U}{U_s} = C_c \left(\frac{I_p}{\pi \left(\frac{dI}{d\Omega} \right)} \right)^{\frac{1}{2}} * \frac{\Delta U}{U_s} * \frac{f_i}{f_o} * \left(\frac{U_s}{U_i} \right)^{\frac{1}{2}}$$

where we make use of the relations

$$M = \frac{f_i}{f_o} * \left(\frac{U_s}{U_i} \right)^{\frac{1}{2}} \quad \text{and} \quad I_p = \frac{dI}{d\Omega} * \pi * \alpha_o^2$$

M is the overall magnification of the system. The spherical and chromatic aberration coefficients C_s and C_c related to the source sided focal length f_o and the ratio U_s/U_i of extraction voltage to final beam voltage. The emission half angle α_o determines the probe current I_p . The intended application determines the final beam voltage U_i as well as the working distance and hence a lower limit for the focal length f_i of the objective lens.

There are mainly two ways of optimizing the performance of the arrangement :

- to find optimum values for the source parameters $dI/d\Omega$ and its energy spread $\Delta E = e * \Delta U$ by varying source geometry, emission current and emitter temperature.
- to optimize the optical parameters, i.e. C_s/f_o and C_c/f_o .

Optimization of the emitter

Since chromatic aberration is dominant in the range of acceptance half angles $\alpha_o = 1.5$ mrad it would be of some interest to reduce the total energy spread of the emitted ions. Generally, the energy spread decreases with decreasing total emission currents, and as there is a discrepancy between the energy spread found for emission currents of about 1 μ A (1-8) and the measurements of Culbertson et al. (9) for which a satisfactory explanation is still missing. We have made some measurements at low emission currents using relatively sharp emitters.

Sharp emitters have a considerably increased flow impedance of the liquid metal due to the smaller total surface leading to the tip. For a sufficient gallium supply a high portion of the total emitter surface must be wetted with the liquid metal.

We are using two different procedures of etching the polycrystalline tungsten emitter which give the same results:

- dc dropoff etching in 2n NaOH and subsequent re-etching of the tip for 1 second to enhance the wettability of the surface.
- ac etching in 2n NaOH until the desired tip radius is attained

In the present investigation we are using tip radii between 0.2 and 0.5 μ m. As wetting may be impeded by oxide or hydrocarbon contamination layers on the emitter (10); the vacuum was kept below $5 * 10^{-8}$ mbar during preparation and operation of the tip.

The mass flow of liquid metal can be enhanced by keeping the source at an elevated temperature up to about 400°C during operation. At this temperature the thermal evaporation rate of gallium from the emitter is still quite low.

Fig.2 shows the current-to-voltage characteristics of two different tips, numbered 12) and 13). The suffixes a) and b) denote two modes of operation: the b)-curves were recorded after heating the emitter up to 600°C for a few seconds while the curves denoted by a) were taken after about 1 hour of emission at low temperatures. Comparing 12a) and 12b) we note that 12a) is shifted towards higher extraction voltages which is probably due to the increased flow impedance.

Fig.3 shows the angular intensity curves of tip 13). The distance between emitter and extraction electrode was 0.5 mm for 12a), 12b) and 13a) while the tip was re-

tracted to a distance of 4.5 mm in 13b) which caused an increase of the extraction voltage from 2.4 kV to 4 kV. The conditions of 13c) are identical to 13b) but the emitter had been exposed to air for some hours.

Insufficient supply of gallium will lead to an unstable emission at higher tip currents or even to sideward emission over the whole current range. We obtain maximum tip currents in the order of 4 μA in the case a) and about 10 μA for the operation mode b) when the tip is heated.

The current at the onset of the emission is usually in the order of .5 μA . Once the emission is started the tip current is stable down to about .2 μA . Below this value we observe a pulsating probe current with varying duty cycles but with nearly constant pulse height and frequency.

Within the stable region of operation the long term drift of the angular intensity is about 15% per hour (Fig.4) and the noise in the probe current is below 1% in the frequency range between 50 Hz and 5 kHz. We have therefore operated the source without any further stabilisation of the emission current. Like other authors (7) we have found that the stability is affected by poorer vacuum conditions.

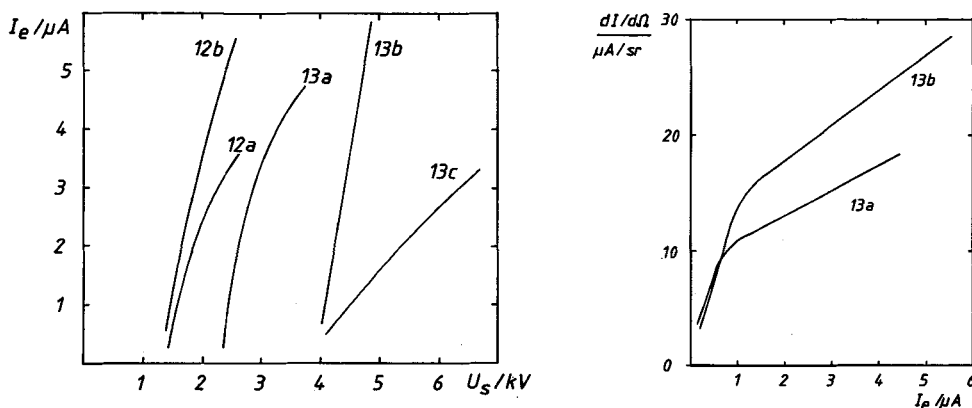


Fig. 2 and 3: Emission current I_e vs. extraction voltage and angular intensity curves for two different emitters (12) and (13). 12a) and 13a) show measurements with reduced supply of liquid metal. The distance between emitter and extraction electrode was 0.5mm for 12a), 12b) and 13a) and 4.5mm for 13a) and 13c).

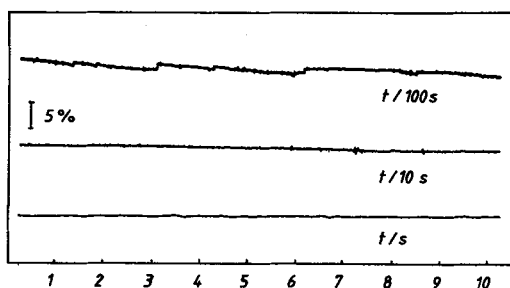


Fig.4: Stability of the angular intensity in operation mode a)

We have measured the energy spread of the emitted ions using a Möllenstedt analyzer which provides an energy resolution better than .1 eV (11). In order to keep the source at good vacuum it was placed into an ultrahigh vacuum chamber mounted on top of the high vacuum column containing the analyzer. A 200 μm diaphragm between HV and UHV served as a differential pumping aperture and at the same time as a limiting aperture for the measurement of the angular intensity.

The intensity distribution below the analyzer is swept over the recording slit by means of electrostatic deflecting plates. The current is collected in a Faraday cage below the recording slit.

The energy distribution curves are nearly gaussian-shaped. Fig.5 shows the FWHM of the energy distribution for two different emitters vs. the total emission current. We note that in case a) the increase of the energy spread of the ions with the total emission current is approximately linear while in case b) where the liquid metal supply is more abundant there is a decrease in the slope of the energy spread curves at low emission currents known from earlier measurements (2,12). Kuby and Siegel (13) have recently tried to attribute the energy spread to the volume of fluid exposed to the high field.

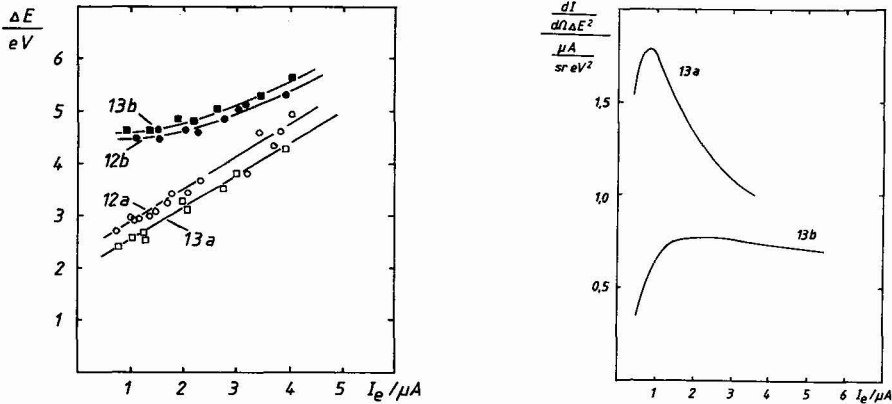


Fig.5 and 6: Energy spread ΔE_{FWHM} and chromatic angular intensity

The reproducibility of measurements with one tip lies within 10-15%. We ascribe this variation to fluctuations of the mass flow.

As the emission current in a) still shows a sharp onset at a given voltage and as the angular intensity curves are quite similar to the ones in b) we assume that the sources still operate in an electrohydrodynamic mode although the emitting feature may be altered by an increased flow impedance compared with b).

In the case where chromatic aberration is dominant the chromatic angular intensity $dI / (d\Omega * \Delta E^2)$ (Fig.6) is the source parameter that determines the current available in a probe of a given diameter (2,8,12). The chromatic angular intensity curves show a sharp maximum at tip currents of about .8 μA in case a) while in case b) this maximum is less pronounced and shifted to tip currents of about 2.3 μA .

Ion optical considerations

The used extraction optics was similar to the asymmetric lens (14) which has been investigated for field emission applications for several times (15,16). We have calculated three other electrode arrangements and compared them for their suitability for ion microbeam applications such as primary ion sources for SIMS applications.

Lens no.2 is identical with no.1 except the center electrode which has been turned around. No.3 is the lens with an asymmetry parameter $n=5$ described by Shimizu (17) and no. 4 is similar to Riddle's lens no. 16 (18).

We have calculated the source sided focal length f_o , the source position z_o , the spherical aberration coefficient C_s and the chromatic aberration coefficient C_c referred to the source side for the case of high magnification. The result of the calculation of the aberrations we have made using the LINPROG program will be published elsewhere in more detail.

Fig.8 represents the relative aberration coefficients C_s/f_o and C_c/f_o of the four lenses for different virtual source positions z_o .

Fig.10 compares spot size d and total brightness β of an ion probe made with a two lens system (Fig.9) consisting of the calculated tetrodes as accelerating lens and an objective lens identical to no.2 operated as an einzel lens.

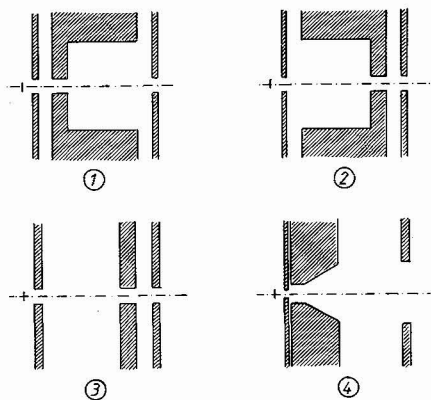


Fig.7 Four different lenses investigated.

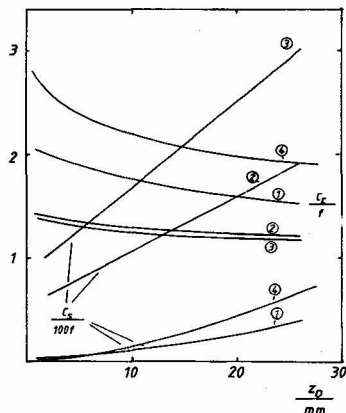


Fig.8 : Relative aberration coefficients of tetrode systems 1-4 vs. source position.

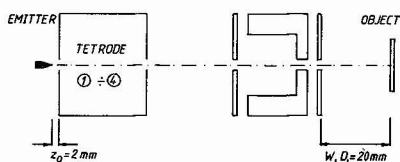


Fig. 9: Schematic drawing of the lens system used.

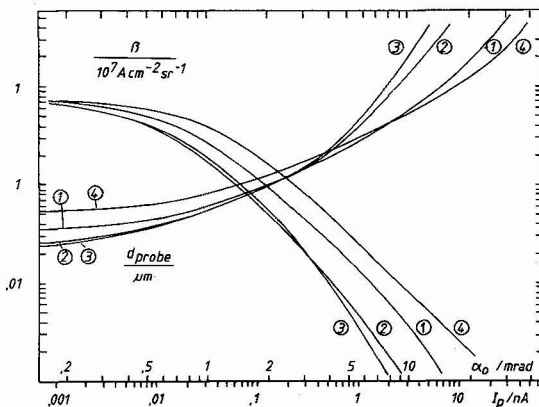


Fig.10 : Spot size and brightness of complete system vs. probe current and acceptance half angle.

On the horizontal axis we have plotted the acceptance half angle α_0 and the beam current I_p on the basis of an angular intensity of $10 \mu\text{A}/\text{sr}$. For the calculation of d and β we used an energy spread of 3 eV , an extraction voltage of $U_e = 3 \text{ kV}$, a final beam voltage of $U_i = 10 \text{ kV}$ and a virtual source diameter of 30 nm . The brightness on the side of the object is strongly influenced by the lens aberrations. For small values of α_0 it converges towards the source brightness which depends on the estimated diameter of 30 nm for the virtual source.

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