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Investigation of New Ionized Cluster Beam Source

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새로운 이온화된 클라스터 빔원의 제작과 특성 조사

고석근 · 장홍규 · 정형진 · 최원국 · S.G. Kondranine · E.A. Kralkina

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Abstract – The present paper represents the results of development and first experimental tests of a new ionized cluster beam (ICB) source. The novelty of ICB source lies in the fact that the crucible and ionization parts are spaced in one cylindrical shell but are not divided in an electric circuit. The ICB source adapts permanent magnets to increase the ionization efficiency. The maximum obtained Cu^+ ion current density is 1.5 μA/cm^2, therewith the ionization rate amounts 3% under deposition rate equal to 0.4 Å/s, and amounts 6% at the denposition rate, equal to 0.2 Å/s. When the deposition rate is 0.2 Å/s and the acceleration voltage is 4 kV, the Cu^+ion beam uniformity is better than 95%.

요 약 – 본 논문은 새로운 이온화된 클라스터 빔원(ionized cluster beam source)의 제작과 특성조사에 관한 것이다. 이온화된 클라스터 빔원의 특성은 도가니부와 이온화부가 하나의 원통안에 놓여있지만, 전기적으로는 서로 분리되어 있지 않다. 이온화 효율을 증대시키기 위하여 영구자석을 배치하였다. 인출할 수 있는 Cu^+ 이온의 최대 전류밀도는 1.5 μA/cm^2 이었으며, 증착율이 초당 0.4 Å일 때 이온화율은 3% 이었으며, 증착율이 초당 0.2 Å일 때는 이온화율이 6% 이었다. 증착율이 초당 0.2 Å이고, 가속전압이 4 kV에서는 Cu^+ 이온빔의 균일성이 95% 이상이었다.

1. Introduction

Many efforts have been undertaken during last two decades to develop useful ionized cluster beam (ICB) technique for high quality thin films [1-3]. In many cases, the films deposited by ICB technique differed markedly from those of the same materials deposited by means of conventional evaporation or sputtering techniques. For examples, they showed important characteristics which can apply thermally stable semiconductor metallization[4,5], high performance optical coationg [6], high reflective x-ray mirror with atomically smooth surface [7], high quality semiconductor and insulator devices [8,9], and organic electron devices[10].

In this paper, basic features of our newly developed ICB source and some experimental results are described. The characteristics of the ICB source lies in the fact that the ionization efficiency can be enhanced by means of magneto-electrical electrons confinement, which prolongs the lifetime of electrons in the ionization region, hence increases the possible number of ionization events.

The presented construction is significantly compact in comparison with the previous models to avoid some troble in ICB source [11] and for the high deposition rate the sufficiently high crucible

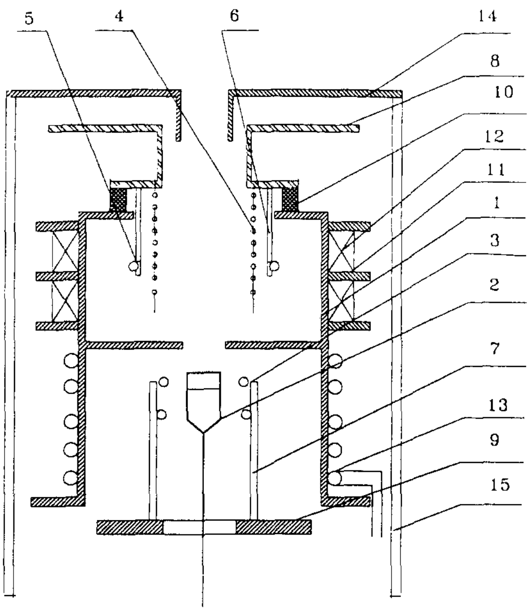

Fig. 1. The schematic diagram of ICB source. ① cylindrical chamber, ② crucible, ③ crucible heating filament, ④ anode, ⑤ thermocathode, ⑥, ⑦ filament supports, ⑧, ⑨ flanges, ⑩ insulator, ⑪ pole pieces, ⑫ magnets, ⑬ cooling system, ⑭ grounded flang, and ⑮ external cylinder.

temperature (up to 2000 K) can be obtained.

The experimental investigations of the ICB source are aimed at the revealing stable operation regimes, which a fine adjustment of the deposition rate in the given range is possible, at the investigation of effective metal atom ionization conditions, at the revealing of conditions of extracting mostly uniform metal ion beam.

In these purposes, following experiments were conducted:

1. Volt-ampere characteristics in the crucible and ionization parts of ICB source.

2. The changes of crucible temperature under various heating procedures.

3. The dependence of deposition rate on the crucible temperature.

4. Ion-beam current and ion-beam profile behavior under the changes of deposition rates and acceleration potentials.

2. Experimental

2.1. The construction of a new ICB source

The schematic diagram of a new ICB laboratory model is shown on Fig. 1. The basic construction of the bearing element represents the cylindrical chamber ①, fabricated in stainless steel and divided into two parts. In the lower part of the chamber, the carbon crucible ② and the crucible heating filament ③, made of W-Re wire with diameter of 0.7 mm are placed. In the upper (ionization) part of the cylinder, the anode ④ and the thermocathode ⑤ (W-Re filament) are arranged. To simplify the replacement of the filaments, the filament supports ⑥ and ⑦ are fixed on the separate flanges ⑧ and ⑨, which are mounted to the main chamber walls through alumina insulators ⑩. The operation of replacing the crucible or refilling the depositing material in the crucible is simplified and can be conducted without removing ion source from the vacuum chamber.

The magnetic system is arranged on the external of the chamber. The magnetic system consists of three pole pieces ⑪, between them the cylindrical permanent magnets ⑫, made in Alnico alloy, are located.

The radiation from the filaments is shield by a molybdenum foil which is installed inside ionization and crucible chambers. The water cooling line ⑬ is also attached at the outside wall of lower chamber.

The acceleration electrodes system is composed of

a) the basic flange ⑧, at which the anode is fixed and b) the grounded flange ⑭, located on the external side of the cylinder ⑮.

The water cooled external cylinder ⑮ serves as a shield for preventing flashovers. The special hole with a 10 mm diameter is made in the middle of lower chamber for the in-situ control and observation of crucible temperature.

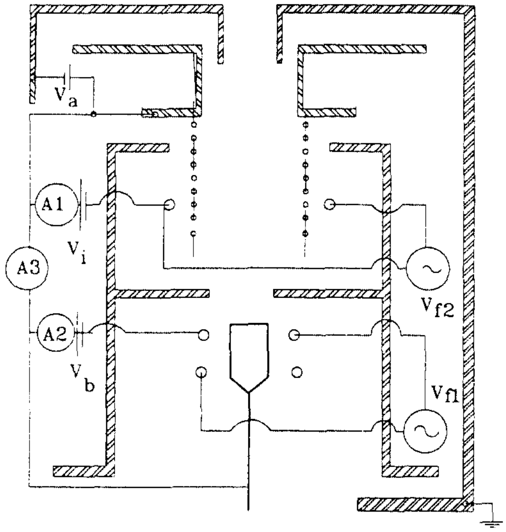

Fig. 2. Electrical scheme iof the new ICB source.

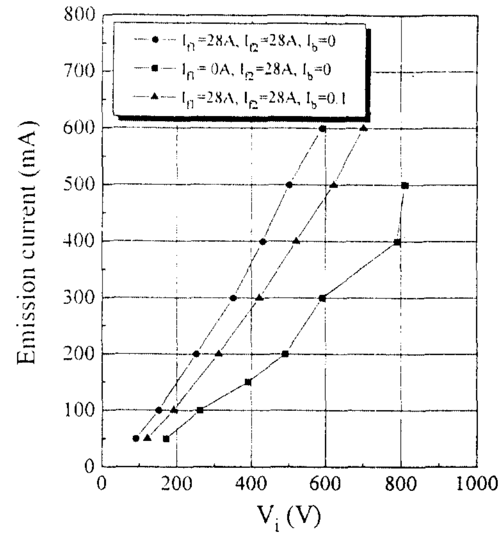

Fig. 3. Dependence of current emitted by thermocathode on the voltage between thermocathode and anode.

2.2. Electrical diagrams

Fig. 2 shows the electrical scheme of the new ICB source adopted in the present investigation. The cylindrical chamber was electrically connected with a crucible heating filament. The insulated shield installed in the ionization chamber was also conducted and the shielding plate was electrically connected with the cathode potential.

During the experiments the operational regimes of the ICB source, utilizing Cu as a working metal, were investigated. Two factors define the quality of ICB source; the value of extracted Cu^{+} ion current density and the uniformity of the ion-beam profile. Thus in the present work both Cu ion-current density and ion beam profile were measured at different operational regimes of ICB source. The measurements were conducted by means of a Faraday cup.

A quartz crystal of thickness monitor (Maxtec Co. TM-103R) was used for monitoring the Cu deposition rate.

The crucible temperature measurement was also conducted from middle part to the top of crucible by using the pyrometer "MINOLTA Tr-630".

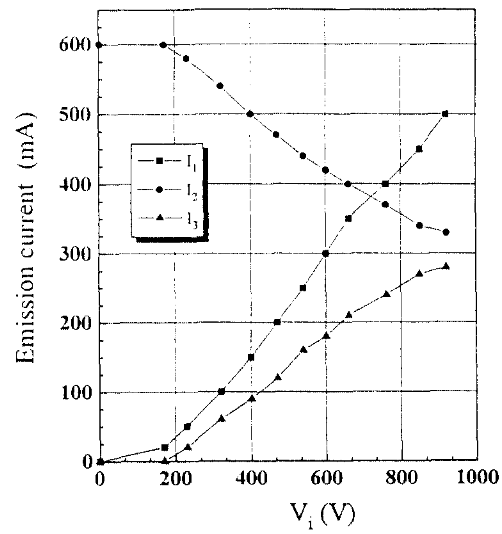

Fig. 4. Dependence of currents I_1, I_2, and I_3 measured by milliampere meters A_1, A_2, and A_3 (see Fig. 2) on the voltage between thermocathode and anode.

3. Results and Discussion

On the first stage of experimental tests of ICB laboratory model the measurements of volt-amp characteristics were carfully carried out. The most

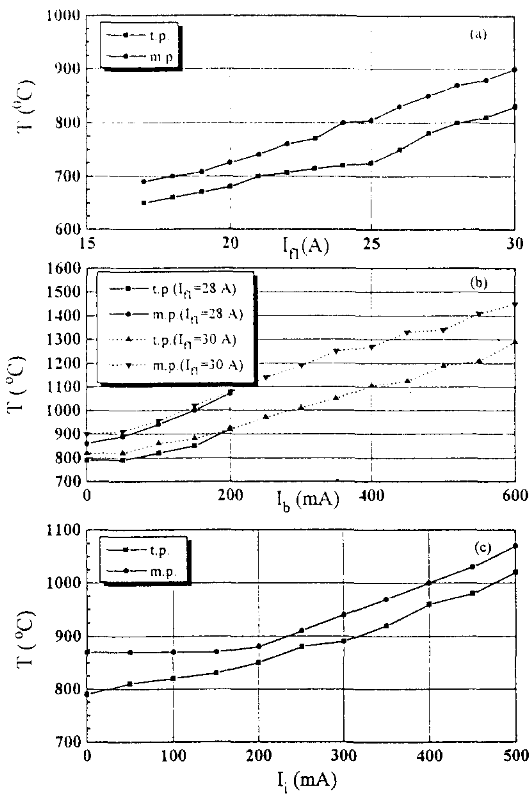

Fig. 5. Dependence of the crucible temperature on (a) heating filament current, (b) current between heating filament and crucible, and (c) emitted current for the thermocathode.

interesting situation was found while working crucible and ionization parts of ICB source simultaneously. These results are shown on Fig. 3. A reasonable increase of current in the ionization power supply circuit takes place due to heating the filament of crucible in case when the bombardment current is zero. As the bombardment current appears, the current in the ionization circuit decreases because part of electrons now are closed to crucible. In the second step of the experiment the more detailed investigation of the ion source volt-ampere (V-A) characteristics with the current control by means of A_3 milliampere meter was conducted. The value of current in this circuit indicates the quota of electrons, accelerated by the

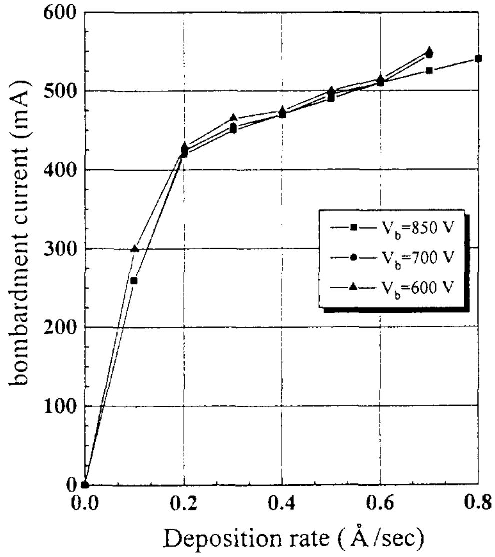

Fig. 6. The required bombardment current for represented deposition rates at different voltages V_b.

voltage between thermocathode and anode V_i and electrically closed through crucible. Fig. 4 shows the experimental results measured the electron current at A_1, A_2 and A_3 in Fig. 2.

One can see that the current of electrons, originated from thermocathode and closed to the crucible (current I_3), increases with the increase of the voltage V_i and the initial current in the milliampere meter circuit A_2 is obviously reduced as the value I_3 increases. The reduction increases with the increase of voltage V_i.

The Fig. 5a demonstrates the dependence of the crucible temperature on the heating filament current. In this case the crucible is heated only by the radiation from the heating filament. One can see that the temperature of the middle part of the crucible is about 100°C higher than that of the top part. If the heating of crucile by electrons from heating filament is added (see Fig. 5b), the crucible temperature increases as well as the temperature difference between the middle and top parts of the crucible. The dependence, represented on Fig. 5b, is given for the two values of heating

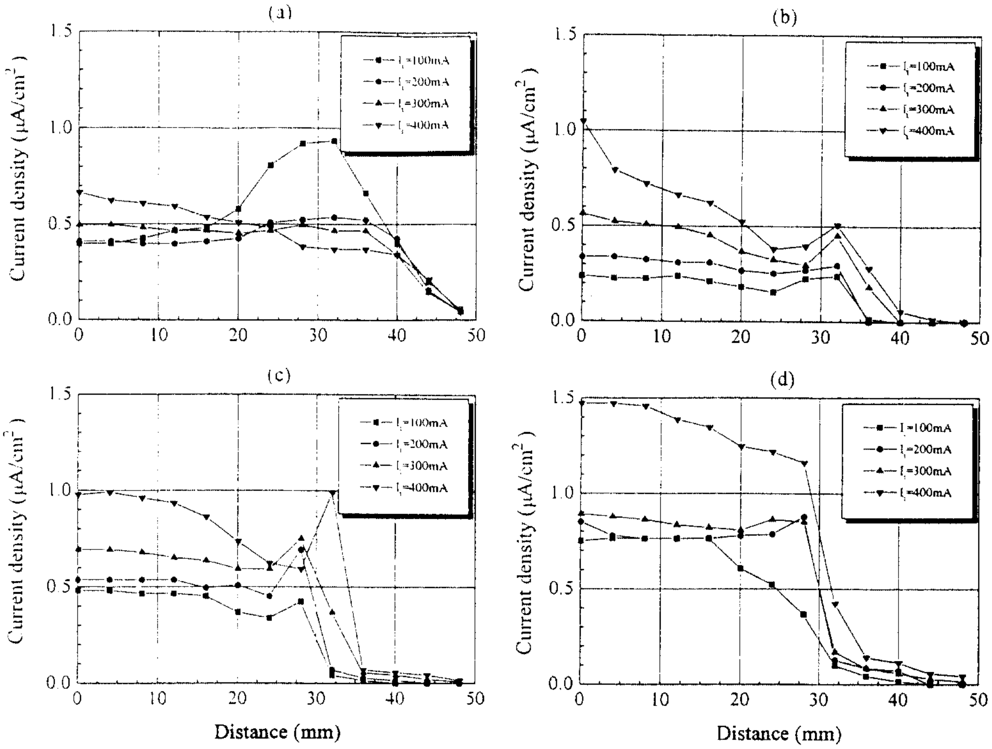

Fig. 7. Beam profiles measured at deposition rate 0.2 Å/s with acceleration voltages 1 kV (a), 2 kV (b), 3 kV (c), and 4 kV (d).

filament current: 28 A and 30 A. In the first case, the voltage V_b between heating filament and crucible, necessary for the identical electron emission current, was exactly two times higher in the case I_{fl}=30 A. Thus, the crucible temperature seems more effectively depend on the filament current than the V_b. The experimental justification of this idea is presented in Fig. 6, showing the bombardment current, needed for achieving the necessary deposition rate with various values of electron energy. Fig. 5c shows the temperature of the crucible heated by the radiation from heating filament and electron current emitted from the thermocathode. One can see that in this case the most homogeneous distribution of crucible temperature was obtained but achieved crucible temperatures were not so high as in the case shown in Fig. 5b.

On the next stage the beam profile investigations were carried out using a Faraday cup. The measurements were conducted at a distance of 15 cm from the exit of the acceleration electrode. In order to cut the electron component the potential equal to-30 V in respect to the ground was applied to the Faraday cup. The investigations were carried out for the deposition rates ranging from 0.1 to 0.4 Å/s, which were determined by bombardment current emitted from the crucible filament, and also for the various acceleration potentials of 1~4 kV, and for the ionization current values of I=100 mA~400 mA. The experimental data are presented on Figs. 7 and 8. The dependence of extracted ion current density on the acceleration potential is attracting attention. First it is worth considering ionization current, equal to 100 mA. In case of accelerating voltage V_{ac} changing from 1 to 4 kV the extracted ion current density changes non-monotonically, at 1 kV the to-

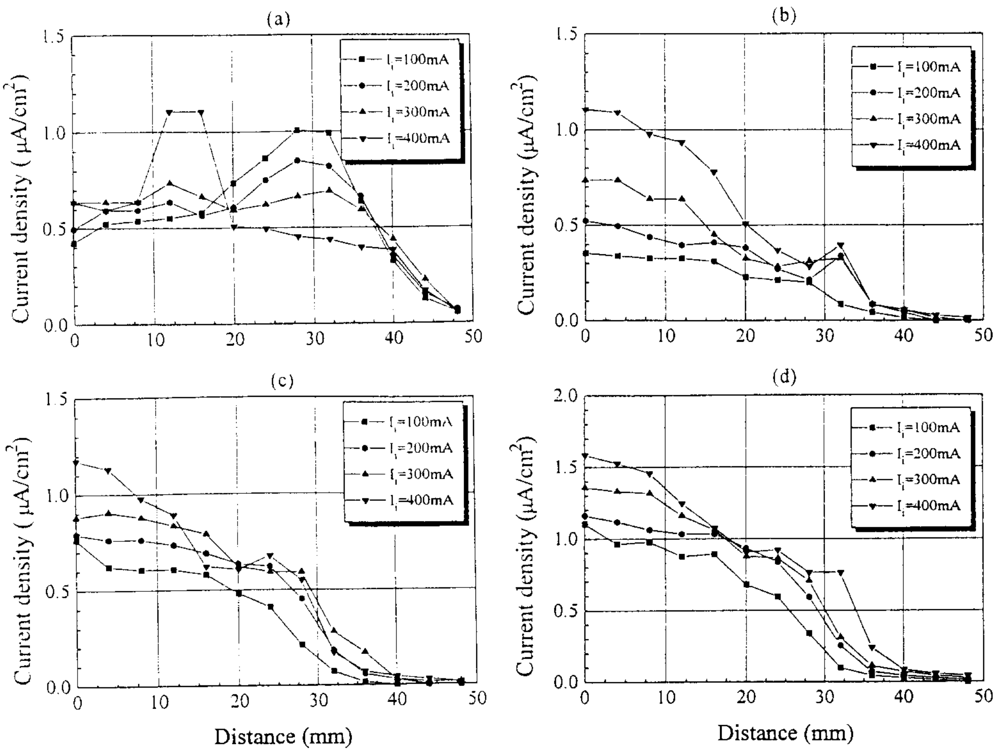

Fig. 8. Beam profiles measured at deposition rate 0.4 Å/s with acceleration voltages 1 kV (a), 2 kV (b), 3 kV (c), and 4 kV (d).

tal current density is maximum, at 2 kV it falls, and then slowly increases with the V_{ac} increase. Such type of dependence is typical for all considered deposition rates, becoming more obvious for the deposition rate equal 0.2 Å/s (see Fig. 7). It must be indicated that in the realm of the high electron currents (I=400 mA) in the ionization part of ICB source, the ion current density monotonously increases with the V_{ac} increase.

At the deposition rate equal 0.2 Å/s and acceleration potential less than 4 kV the ion beam profiles are non-monotonic ones. Most probably at I=100 mA and V_{ac}=1 kV there are the optimal conditions for ionization in the ionization and acceleration area, so the absolute values of extracted ion current are hight. However, the spatial distribution of electric fields in inoization part cause the defocusing of the ion beam. The best beam profile from the viewpoint of its uniformity has been observed with the high values of V_{ac}=4 kV. With the increase of deposition rate from 0.2 Å/s up to 0.4 Å/s, the uniformity of Cu^+ ion beam essentially worsens.

The maximum obtained Cu^+ ion current density on the probe amounts for 1.5 μA/cm², therewith the ionization rate amounts 3% under the deposition rate equal to 0.4 Å/s, and amounts 6% at the deposition rate, equal to 0.2 Å/s.

4. Conclusions

Characteristics of the newly ICB source are as follows.

1. Tests of ICB source showed that at the deposition rate equal to 0.2 Å/s and acceleration voltage less than 4 kV the ion-beam profiles are non-

monotonic ones. The best beam profile from the viewpoint of its uniformity has been observed at the deposition rate 0.2 Å/s with the high values of acceleration voltage V_{ac}=4 kV. With the increase of deposition rate from 0.2 Å/s up to 0.4 Å/s, the uniformity of ion current density essentially worsens.

2. Tests of ICB source showed that in the realm of the small electron currents (~100 mA) in the ionization part of ICB source the ion current density changes non-monotonically with increasing acceleration voltage V_{ac}, at 1 kV the total current density is maximum, at 2 kV it falls, and then slowly increases with the increase of V_{ac}.

3. Tests of ICB source showed that in the realm of the high electron currents (~400 mA) in the ionization part of ICB source the ion current density monotonously increases with the increase of the acceleration voltage V_{ac}.

4. The maximum obtained ion current density on the probe amounts for 1.5 μA/cm^2, therewith the ionization rate amounts 3% under the deposition rate equal to 0.4 Å/s, and amounts 6% at the deposition rate, equal to 0.2 Å/s.

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