THE ION EMISSION FROM THE PLASMA FORMED IN FERROELECTRIC SOURCE

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The experimental studies of active plasma source are presented. The plasma was formed by a noncomplete discharge on the surface of ferroelectric $BaTiO_3$ samples. We received the spectrum of the discharge using the optical emission spectroscopy method. The spectrum lines corresponded to the atoms and ions of elements related to the ferroelectric (Ba, Ti, O) and residual atmosphere (N). The intensity of the spectrum lines relied on the discharge current and slightly changed depending on the residual gas pressure in range 10^{-5} - 10^{-3} Torr. Under the negative bias voltage the ion current in plasma source was registered.

Keywords: active plasma source; ferroelectric; driving pulse; ion beam; optical spectroscopy.

Introduction

One of the sources of particle beams is the active plasma formed by the discharge on the surface of ferroelectric materials ($BaTiO_3$, PZT, PLZT) [1, 2]. The formation of the discharge has a number of features in comparison with the explosive electron emission [3, 1]. Firstly, we would note the low voltage of discharge initiation that's equal to a few kilovolts. Secondly, the discharge has a noncomplete stage and is characterized by a multichannel structure [1]. This provides the formation of plasma sheet with high uniformity on the ceramic surface.

At present, the cathodes based on ferroelectric $BaTiO_3$ and PZT were intended for the electron beams formation with energy of a few hundred kilovolts [1, 4]. Furthermore, the source of ion beams can be realized using this type of cathode [5]. Due to the features of discharge mentioned above the plasma layer can be homogeneous on the electrode surface with big area. This is an important requirement for the plasma source of ion diodes, since the surface area of electrode is usually more than 100 cm^2 and its profile has a focusing geometry [6]. From this point of view the investigations of ion emission from plasma formed under the noncomplete discharge in the ferroelectric active source are relevant.

Experimental results

The ferroelectric source was designed from the several $BaTiO_3$ segments fixed on the dielectric base (Fig. 1). In experiments the plasma source included five cylindrical $BaTiO_3$ segments; the diameter and thickness of each one were 40 mm and 20 mm, respectively. From the side of base all segments had metal disk electrodes (20 mm in diameter) connected to each other by a substrate. The front side of segments was covered by the electrode having an outer diameter of 120 mm and made of stainless still grid (5×5 mm mesh, 0.5 mm diameter of wire). The front electrode was fixed relative to the dielectric base and was grounded. The total area of the surface of $BaTiO_3$ segments under the front electrode was 60 cm^2.

The ion was emitted under the negative bias voltage which applied to the collector. In this case the electron current was closed in the middle electrode placed between the front electrode and collector. The middle electrode was made of stainless steel grid with transparency of 90% and had outer diameter of 160 mm. As a result, the electric field of the bias source was localized and actually did not affect on the plasma formation on the ferroelectric surface. The ion current closed to the collector was measured using several resistors. The capacitors realized the separation of measuring circuit from bias voltage.

The plasma formation on the ferroelectric surface under the driving voltage was accompanied by an increase in the residual gas pressure in the region of front electrode. This is the result of evaporation the ferroelectric

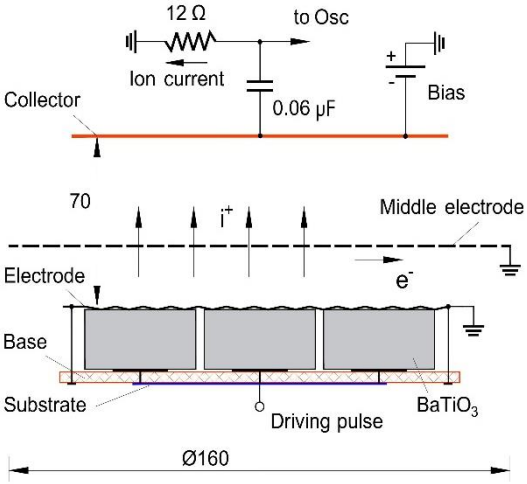

Fig. 1. Configuration of ferroelectric plasma source

material and desorption of neutral particles from its surface under the discharge current. The waveforms of voltage on substrate and discharge current through the ferroelectric are shown in Fig. 2.

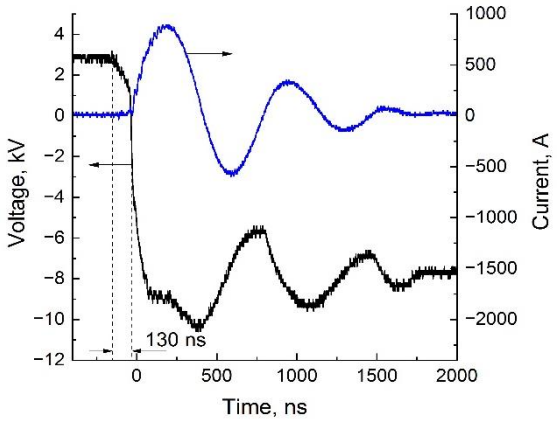

Fig. 2. Waveforms of voltage on substrate and discharge current

The plasma formation was started on the front of driving pulse. During the first 130 ns we observed the delay of front of discharge current. During this time the voltage on substrate was changing very slow and the current value have been zero. The subsequent rise of the current front was accompanied with plasma formation on ferroelectric surface. The relative change in the voltage during the time delay was ~2 kV.

Under the negative bias voltage on collector we investigated the ion emission. The separation of the electron and ion flows happened with bias voltage less than -0.5 kV. The typical signals of ion current synchronized with current are presented on Fig. 3.

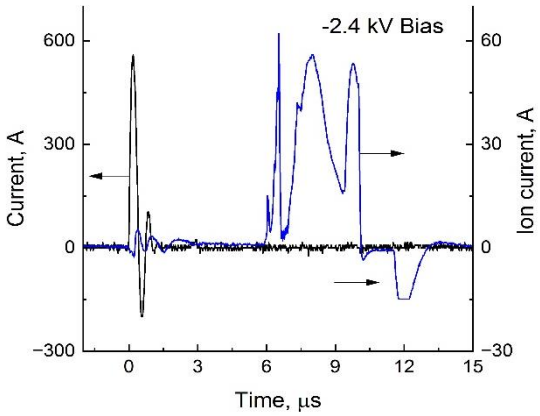

Fig. 3. Signal of ion current

The ion current pulse was registered with 6 μs delay relative to the front of current. It should be noted that the ion current pulse consisted of several combined peaks. The total length of current signal was 4.5 μs, the delay time did not change with increasing of bias voltage up to -2.4 kV. When the bias of collector was -2.4 kV the negative signal at the back front of the ion current was registered (marked in Fig. 3). This signal indicated to the electron current formed as a result of secondary ion-electron emission due to the ions flow through the middle electrode.

The collector current increased from 35 to 60 A in the bias voltage range -(0.5-2.4) kV. Based on the collector position relative to the front electrode of the source and the time delay of the front of current signal, the velocity of ion flow was estimated as ~1.2 cm/μs. The charge of ions extracted from plasma and calculated by integrating the current signal, had value of 140 μC at bias voltage -2.4 kV.

To determine the parameters of plasma we used the optical emission spectroscopy. The spectra were recorded by Avaspec 3648 spectrometer in the wavelength range of 200-800 nm, the signal integration time was 1 s. The fiber optic cable was installed at 50 mm distance from the front electrode. Identification of individual lines of atoms and ions of the emission spectrum $I(\lambda)$ (with centers at $\lambda_{(0)i}$, FWHM $\Delta\lambda_{1/2}$ and peak intensity $I_{0(i)}$) was carried out by comparing

them with the data of the NIST Atomic Spectra Database ver. 5.4. The characteristic optical spectrum of discharge is shown in Fig. 4.

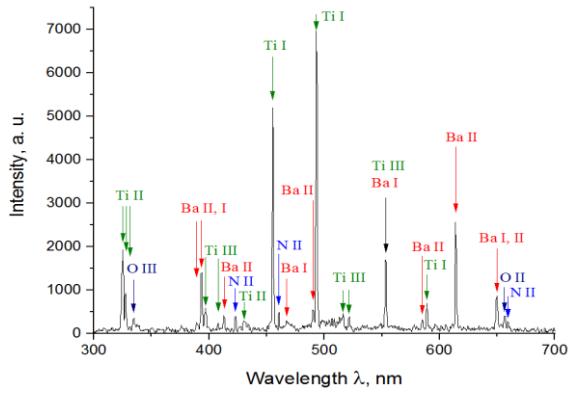

Fig. 4. Emission spectrum at a residual pressure in the chamber of $1 \cdot 10^{-4}$ Torr

The spectrum consisted of lines identified with neutral atoms and ions of elements (Ti, Ba, O) present in the ferroelectric samples. Also there were lines of nitrogen atoms and ions (N I, II) in spectrum, that indicates the participation of the adsorbed gas layer in the plasma formation on the ceramic surface.

The spectral lines of oxygen ions (O II, III) are inferior in intensity to the lines of titanium and barium ions. The intensity of the lines associated with nitrogen atoms and ions turns out to be lower than for the lines of titanium and barium ions with similar wavelengths. The intensity of the broad bands, which can be identified with carbon, nitrogen and oxygen molecules in the ranges of 410-440 nm, 500-520 nm, and 530-570 nm, was also very weak (Fig. 4). The contribution to the emission spectrum from carbon ions was negligible. In addition, we investigated the intensity of spectral lines depending on the discharge current in range (450÷900) A. The magnitude of current changed by adjusting the driving voltage on the substrate from -5 kV to -10 kV. It was found the lines intensity of spectrum was growing with increasing the current. In this case, the change of lines intensity of ions Ti and Ba was correlated with the intensity of their atoms.

Conclusion

Electrophysical and optical emission characteristics of a noncomplete discharge on the surface of ferroelectric $BaTiO_3$ samples were studied in a vacuum of 10^{-5}-10^{-3} Torr. The emission spectra of the plasma are represented by lines of neutral atoms and ions of titanium, barium, and oxygen extracted from the ferroelectric under the discharge. In addition the spectrum had lines of nitrogen atoms and ions generated in the processes of desorption and dissociation of molecules of adsorbed gases. The elemental composition of the plasma remains stable during changing the discharge current and the pressure of residual atmosphere. The change in the concentration of titanium and barium ions correlates well with the change in the concentration of nitrogen atoms and ions.

Funding

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