The Electric Discharge in Superhigh Density Gas at Current Amplitude up to $5{\cdot}10^5$ A

A.A. Bogomaz[1], A.V. Budin, M.E. Pinchuk[2], Ph.G. Rutberg[1], A.F. Savvateev

Institute of Problems of Electrophysics of Russian Academy of Sciences (IPE RAS)
Dvortsovaya nab. 18, St.-Petersburg, 191186, Russia
phone (812)-117-66-23, fax (812)-117-50-56
[1]rutberg@iperas.spb.su, [2]pinchme@mail.ru

Abstract – The investigations of powerful discharge in high density hydrogen were carried out on an installation with preliminary adiabatic compression. The experiments were performed under the following conditions: stored energy of the capacitive storage 140–450 kJ, charging voltage 8.0–14.0 kV, discharge current amplitude 200–600 kA, current rise rate 10^9–10^{10} A/s. The maximum particle density n_{max}, achieved just before the discharge, was about $2.0{\cdot}10^{22}$ cm^{-3}. Arc parameters were calculated on the basis of the channel model. It is shown that increase of the initial density of particles at increase of a current rate of rise results in reduction of arc diameter with increase of channel temperature.

The investigation results of power pulse electric discharge in hydrogen with preliminary adiabatic compression at current amplitude $(1–2){\cdot}10^5$ A are presented in [1, 2].

Modernization of the experimental installation resulted in increasing of current rate of rise from 10^9 A/s to 10^{10} A/s. Current amplitude was driven to $5{\cdot}10^5$ A. The construction of a diagnostic window of 3 mm, made of high impact strength organic, was designed for optical measurements. It has permitted to obtain a photostreak of the discharge channel and its photo.

The discharge was initiated after the adiabatic compression up to 100–180 MPa in the discharge chamber just before the discharge. It was corresponded to maximal hydrogen molecule concentration above 10^{22} cm^{-3}. Oscillogram of pressure in the discharge chamber is shown in Fig. 1.

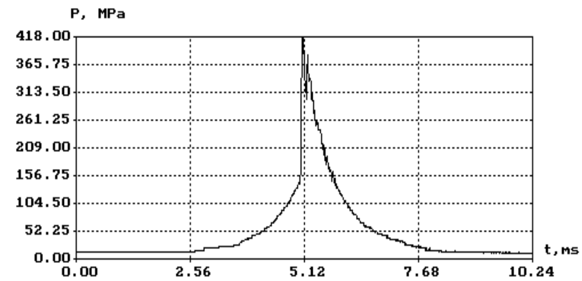
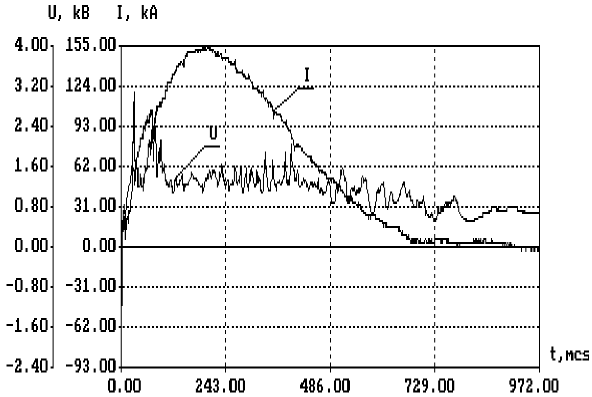
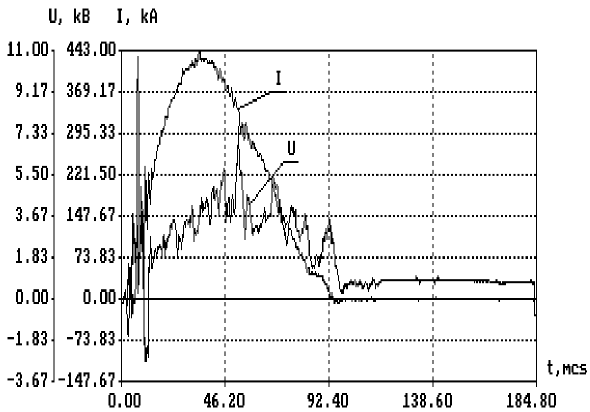


Fig. 1. Oscillogram of pressure in the discharge chamber for dJ/dt – 10^{10} A/s. The adiabatic compression to pressure of about 150 MPa occurs before time 5.1 ms. After that the electric discharge is initiated

The dynamic volt-ampere character is changed at current amplitude increasing up to $5{\cdot}10^5$ A at increasing of its rate of rise. Oscillograms for the electric current and voltage in the discharge gap are presented in Fig. 2 for different current rates of rise. It was found that the strength of field and near electrode voltage drop values increase with initial gas density [1, 2] and with increasing of current rate of rise (Figs. 3, 4). The values of near electrode voltage drop were obtained from extrapolation of interelectrode gap length on zero.



a



b

Fig. 2. Oscillograms of current and arc voltage: a – dJ/dt – 10^9 A/s; b – dJ/dt – 10^{10} A/s

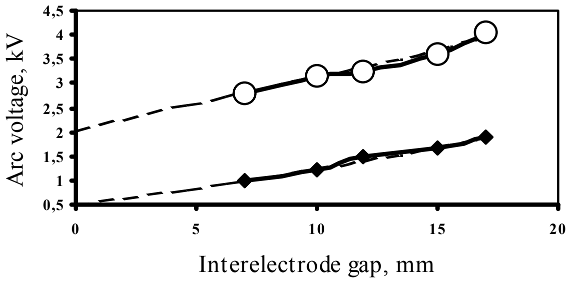


Fig. 3. Arc voltage vs interelectrode gap length: ♦ – d*J*/d*t* – 10^9 A/s; O – d*J*/d*t* – 10^{10} A/s

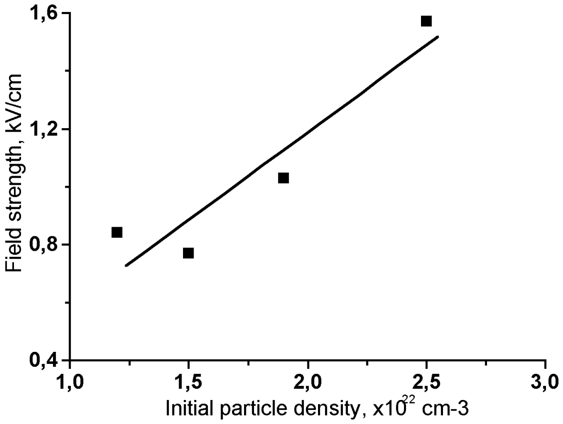


Fig. 4. Field strength vs initial particle density

The photostreak in visible spectrum is presented in Fig. 5. The split was perpendicular to the axis in the middle of the discharge gap. In Fig. 5,a photostreak of the discharge channel was made at initial hydrogen pressure of 5 MPa without preliminary adiabatic compression. Fig. 5,b corresponds to the preliminary compression to 110 MPa. In the first case the maximal channel contraction was observed to radius ≤ 0.8 mm. In the second case the minimal radius was 1.9 mm, which corresponds to weak glow in the photostreak. Increasing in arc voltage and dropping or "peculiarity" in the discharge current corresponds to the moment of the channel contraction. It ought to be mentioned that sometimes several channel contractions or one but more strong are observed according to the voltage oscillograms. Usually time from the discharge initiation to channel contraction increases at increasing of hydrogen initial particle density before the discharge.

Channel contraction can take place both before and after current maximum. At the moment of maximum channel contraction the intensity of radiation in visible part of spectrum decreases sharply.

The discharge channel parameters were estimated in two extreme cases: the discharge burns in pure hydrogen (initial concentration of hydrogen is ~10^{22} cm^{-3}) and discharge burns in metal vapour of initiating wire.

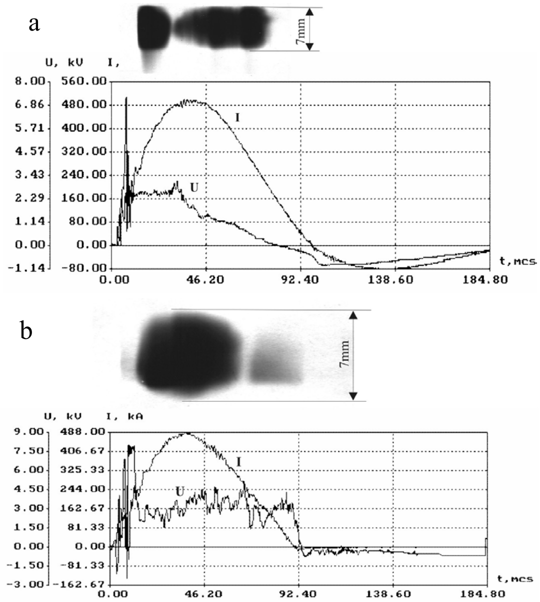


Fig. 5. Photostreak, current and voltage: a – initial hydrogen pressure 5 MPa, b – 110 MPa

In the first case the radiation in the channel is recombination-braking. Plasma is transparent. The system of equations has the following form:

$$\begin{cases} IE = \left(An_i^2T_0^{1/2} + Bn_iT_0^{-1/2}\right)\pi r_0^2; \\ 2n_0kT_0 = P + C\dfrac{I^2}{r_0^2}; \\ \dfrac{E}{I} = \dfrac{1}{\pi r_0^2\sigma(T_0,n_0)}; \\ n_i = n_e \approx n_0. \end{cases}$$

Here T – channel temperature, n_i – ion concentration, r_0 – channel radius, σ – conductivity, P – pressure after adiabatic compression, I – current, E – strength of field. The system decision give $T = 3\cdot10^5$ K, $n_0 = 1.0\cdot10^{21}$ cm^{-3}, $r_0 = 0.06$ cm.

In the second case the optical density of the channel is high. Therefore it was considered that it radiates as a black body. In this case from the system

$$\begin{cases} IE = 2\pi r_0\sigma_bT^4; \\ (1+\bar{z})kT_0 = P + C\dfrac{I^2}{r_0^2}; \\ \dfrac{E}{I} = \dfrac{1}{\pi r_0^2\sigma(T_0,n_0)} \end{cases}$$

we receive result $r_0 = 0.2$ cm, $T = 1.25\cdot10^5$ K, $n_0 = 10^{20}$ cm^{-3}.

Conclusion

Estimations show that experiment corresponding conditions in Fig. 5,a is more suitable to burning arc in hydrogen. The condition in Fig. 5,b closely corresponds to arc burning in initiating wire vapour, its radius of expansion on this condition is 0.2 cm according to independent estimations and close to the measured channel radius. Field strength and near electrode voltage drops are increasing as current rise rate and initial particle density increase.

This work is partially supported by the Russian Fund of Fundamental Investigation (RFFI), project No. 02-02-16770.

References

[1] A.A. Bogomaz, A.V. Budin, V.A. Kolikov, Ph.G. Rutberg, A.F. Savvateev, "*Physics of Extreme State of Substance-2003*," edited by V.E. Fortov et al., Chernogolovka, IPCP RAS, 2003, p. 164 (in Russian).

[2] A.F. Savvateev, A.A. Bogomaz, A.V. Budin, V.A. Kolikov, Ph.G. Rutberg, High Temperature **41**, No. 5, 580 (2003).