acta phys. slov. 32 (1982), No. 3—4

EXPLOSIONS OF THIN Cu AND Al WIRES[1]

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The physical interpretation of experimental data gained by explosion of Cu and Al wires is given. The experimental data were obtained from measurements of current and voltage on the exploding wire and from optical spectra of the arising plasma. The explosions of wires were realized in air under atmospheric pressure and in water, too.

ВЗРЫВЫ ТОНКИХ ПРОВОЛОК ИЗ МЕДИ И АЛЮМИНИЯ

В работе дается физическая интерпретация экспериментальных данных, полученных при взрывах проволок из Cu и Al. Экспериментальные данные получены на основе измерений тока и напряжения на взрывающейся проволоке, а также оптических спектров образованной плазмы. Взрывы проволок проводились в воздухе при атмосферном давлении, а также в воде.

I. INTRODUCTION

In dependence on a given energy the final products of exploding wires were pieces of metal, metal drops or very fine dispersing elements [1]. By a quick increase of electric energy in the wire the author of paper [2] introducing the wave of evaporization, explained the explosion as surface evaporization of neutral gas from a liquid electrically conducting cylinder. In paper [3] the explosion was explained by the forming of thermal fluctuations in an overheated liquid and in [4] by disruption of metal structures equal in lengths to the mean free path of electrons at the temperature of explosion. Processes such as these are very rapid, independent experimental data might confirm one of the above theories or they may provide data for the elaboration of a more general theory.

II. THE WIRE EXPLOSION — EXPERIMENTAL RESULTS

Experiments with exploding wires were made with the help of a generator or a quasirectangular impulse [5]. Cu and Al wires were used. We paid more attention

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[1] Contribution presented at the 3rd Symposium on Elementary Processes and Chemical Reactions in Low Temperature Plasma in Krpáčovo, September 22—26, 1980.

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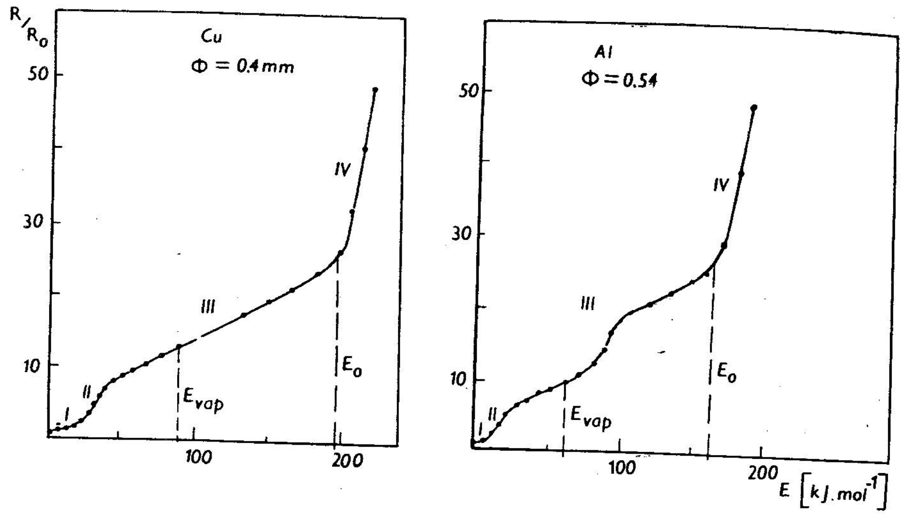

Fig. 1. The dependence of electric resistance of exploding Cu and Al wires on the supporting energy. I — solid phase, II — phase transition solid phase — liquid, III — liquid phase, IV — phase transition liquid — gas, E_{vap} — energy of evaporization at the equilibrium phase transition liquid — gas, E_0 — the initial energy of the phase transition overheated liquid — gas.

to copper as we had Cu wires in a quite wide range of diametres from $\Phi = 0.08$ mm to $\Phi = 1$ mm together with values of parameters of liquid copper.

From the oscilloscopic registration of current and voltage we determined graphically the dependence of resistance on the supplied energy, Fig. 1. The slow increase of Cu resistance up to an energy of ~ 25 kJ mol^{-1} corresponded to heating a wire in the solid phase, the more rapid increase of resistance in the energy interval from 25 to 40 kJ mol^{-1} corresponds to the phase transition liquid — gas. We could see that by a quick heating of the wire overheated liquid was formed. Fig. 1 shows that Cu wires were uniformly heated up to the energy E_0, which corresponded to the temperature 6×10^3 K. The heating of an Al wire in the overheated region was not uniform, which appeared as a nonlinear increase of resistance.

The rapid increase of resistance at energies $E > E_0$ is called an explosion of thin wire. The theories of explosion described in [2] and [3] were verified by explosions of parallel combination wires of different diameter so that the total cross-section of wires was the same in each experiment. In their existence the wave of evaporization had to be the time of explosion different in different combinations. Our experiments with Cu wire of a diameter $\Phi = 0.4$ mm, with 10 parallel wires of diameters $\Phi = 0.125$ mm and with a foil 5×0.1 mm^2 did not confirm the existence of the wave of evaporization and so we supposed that volume processes played a decisive role.

In an overheated liquid there arose growth points of gas due to thermal fluctuations. Growth points with a diameter greater than r_{crit} were capable of an independent existence [5]. The growth points with undercritical values ceased. The increase of the critical growth points was limited by the kinetics of the liquid elements evaporization into the overcritical growth point. According to [6] in an overheated liquid the speed of growth of temperature must be from 10^8 up to 10^9 Ks^{-1}. In our experiments the speed of heating was from 0.75×10^9 up to 1×10^9 Ks^{-1}.

From Fig. 1 there could be determined the energy consumption during the phase transition liquid — gas. Comparing our experimental value with the tabular value of phase transition [7] we ascertained that only 20 % of the liquid metal passed into the gaseous state during the explosion. The concentration of the created metal vapour had the value $n_a \sim 5 \times 10^{25}$ m^{-3}. Spectroscopic measurements of vapour plasma metals showed that optical spectra have a strong continuous background and there appeared a self-absorption of spectral lines [8]. In Al spectra no surrounding lines appeared, while in Cu plasma spectra we could observe them [9]. From spectroscopic measurements [8, 9] we determined that the concentration of plasma Cu wires in the air was $n_e \sim 3 \times 10^{24}$ m^{-3}, the temperature $T_e \sim 1 \times 10^4$—2×10^4 K. For such a plasma the Debye screaning radius had values from $r_D \sim 1.8 \times 10^{-8}$ to 2.2×10^{-8} m and the de Broglie wave length from $\lambda_D \sim 1.1 \times 10^{-9}$ to 1.5×10^{-9} m.

III. DISCUSSION OF RESULTS

Our experiments confirmed the existence of metastable liquid. Magnetic pressure on the surface of the liquid wire was equal to zero, but the value of magnetic pressure on the electrons close to the surface reached the values from 2×10^7 to 4×10^7 Pa. In the case of Al the nonlinear growth of electric resistance in the metastable region could be explained by the formation of an Al_2O_3 layer on the surface of the cylinder with the liquid. The layer hindered the escape of gas from the cylinder, and a higher overheating of the conductive Al part took place together with a finer dispersion of Al when compared with the Cu dispersion. The finer dispersion of Al particles was confirmed in our experiments with exploding wires in water, too. After two or three days the Cu particles settled on the bottom of the vessel, while the Al particles remained diffused in the solution much longer. Our consideration was further confirmed in the optical spectra of the plasma of exploding Cu and Al wires. The spectra of the plasma of the exploding Cu wire were of an atomic character, but the Al spectra in the range from 500 to 600 nm had the character of molecular spectra.

The acquired data on plasma parameters indicated that the plasma of an exploding wire was a dense low-temperature plasma with the degree of the nonideal $\gamma = 0.1$ to 0.35. The values of the Debye screening radius and the de Broglie wave length for electrons showed that in the description of transport phenomena of plasma it is sufficient to use the approach of classical physics.

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Received October 20th, 1980