Vacuum 101 (2014) 257–266

Contents lists available at ScienceDirect

Vacuum

journal homepage: www.elsevier.com/locate/vacuum

Effects of surface treatments on photoelectric work function of silver–nickel alloys

Mohamed Akbi [a, b, *], Aïssa Bouchou [c], Mahdjoub Ferhat-Taleb [c]

[a] Laboratoire "Arc Electrique et Plasmas Thermiques", CNRS, UPRES-A 6069, 24, Avenue des Landais, F-63177 Aubière Cedex, France
[b] Department of Physics, Faculty of Sciences, University of Boumerdes (UMBB), Independence Avenue, 35000 Boumerdes, Algeria
[c] Faculty of Physics, University of Algiers (USTHB), 16000 Algiers, Algeria

ARTICLE INFO

Article history:
Received 25 April 2013
Received in revised form
30 August 2013
Accepted 2 September 2013

Keywords:
Electron work function
Photoemission
Fowler's methods
Contact materials
Electric arc
Cathode phenomena

ABSTRACT

Theoretical models of arc roots need a good knowledge of physical constants characterizing contact material. With pure metals, all the constants are well known, whereas for the new industrial materials made with silver alloys some of these parameters are still not known. The purpose of this paper is to get a better understanding of emission of electrons occurring in an alloyed cathode submitted to several vacuum outgassing cycles at room temperature and residual gas pressure of 1.4×10^{-7} mbar. The electron work function (EWF) of silver alloyed contacts, Ag–Ni (70/30), was measured photoelectrically, using Fowler's method of isothermal curves.

Experimental results about silver–nickel alloys show a large dependence of obtained results with the preparation of contact surface. The EWF of the contact pastille made with silver alloys Ag–Ni varies with surface cleaning by vacuum outgassing cycles. For an unpolished contact, the EWF varies between 4.34 eV and 4.51 eV (the EWF of Nickel), after 7 cleaning cycles and cleaning time of 9 days. On the other hand, for a polished contact, the EWF varies between the EWF of the two components, namely from 4.26 eV for Ag to 4.51 eV for Ni, at room temperature, after 22 cleaning cycles and a cleaning time of 16 days. The error in determining EWF was ±0.03 eV. A multilayer model, taking into account the strong intergranular and volume segregation gives a good interpretation of the obtained results. In addition, a change of order of 0.1 eV was observed for silver alloys Ag–Ni (60/40) EWF after polishing. Afterwards, the microstructure of the contact surface was analyzed with scanning electron microscopy (SEM) and energy dispersive x-ray spectrometry (EDS). The analyzes of the cathode surfaces before and after polishing enabled us to have evidence about the decrease of the electron work function for polished samples.

1. Introduction

Modelization of phenomena describing arc root evolution needs accurate data on material that gives rise to it. Several authors [1–3] have shown that surface state and its composition from initial ones have an effect on cathodic spot duration, on their dimension and cathode erosion; this is due to electron crossing from electrode metallic state to plasma state of ionizing region. In this case, presence of materials different from basic one or existence of micro tips yields electric fields which extract electrons.

Moreover, theoretical research works made in LAEPT laboratory (Clermont-Ferrand, France) [4] have shown that a little variation about work function, gives change on physical parameters of cathodic spot (temperature, radius, electric field, ...). For example, an increasing of 0.1 eV of Electron Work Function (EWF) gives, for an electric arc carrying a 1000 Amps current, an increasing of 100 K on cathodic temperature.

Alternatively, an improvement has been made on the theoretical basis of electrical arc with the aid of a simple model for the electronic properties of a metal surface, called the jellium model [5,6]. The electronic structure of surfaces manifests itself in the surface properties, like the surface conductivity and work function. In the Jellium model, the ion cores are replaced by a uniform background of positive charge with density equal to the spatial average of the ion charge distribution. In other words, one can say that this model considered the atoms of the solid metal as positive ion cores in a sea

* Corresponding author. Department of Physics, Faculty of Sciences, University of Boumerdes (UMBB), Independence Avenue, 35000 Boumerdes, Algeria. Tel.: +213 24816420; fax: +213 24816284.
E-mail address: akbim656@gmail.com (M. Akbi).

0042-207X/$ – see front matter
http://dx.doi.org/10.1016/j.vacuum.2013.09.003

of free electrons. The values of the work functions calculated for simple metals within a framework of the jellium model demonstrate reasonably good agreement with the experimental results [7]. A. Anders had pointed out that a metal with different crystalline surfaces evinces differences in the work function [8], so it became imperative to measure this physical parameter with accuracy. Nonmetallic atoms and films recovered generally cathode surfaces. Adsorbates and roughness affect the work function and the electric surface field. Any surface is subjected to impingement of the atoms or molecules of the gas the surface is exposed to. The presence of adsorbates changes the work function. Anders explained as follow how charge transfer from and to adatoms occurs on a metal surface: on one hand, the adatom has an occupied electronic state above the Fermi level of the metal, and thus full or partial electronic charge transfer from the adatom to the metal will occur, causing a net positive charge of the adatom, reducing the work function. On the other hand, the adatom may have an unoccupied state slightly below the Fermi level, which causes electron transfer from the metal to the atom and an increase of the work function [8].

In addition, similarities between arc discharges in the cathode material vapor in vacuum environment and arcing phenomena in tokamak fusion devices have been already pointed out 50 years ago [9]. Arc discharges burning in the vapor of cathode material in a low pressure or vacuum environment, the so-called vacuum arcs, have been investigated for a long time. Electrode materials, i.e. binary and ternary alloys such as CuCr, CuW, and AgWC, have been developed and used in numerous industrial applications, primarily for vacuum circuit breakers, vacuum arc switches, etc. It has been widely assumed that arc discharges are usually initiated by explosive emission processes [10]. The surface conditions, in particular the surface microstructure, contamination layers and dielectric inclusions influence sensitively the discharge initiation. The surface conditions may be substantially changed by continuous discharges or other cleaning processes, leading to an increase of the breakdown voltage by up to an order of magnitude [11,12]. In the present work, the effects of cleaning by vacuum outgassing on EWF for silver–metal alloys have been thoroughly highlighted. Further, the arc spot which has a short lifetime τ of the order of 10 ns moves by jumps over longer distances. This is induced usually by surface irregularities, contamination layers or particles. Jüttner gave a qualitative picture of the crater development with time [13], the question arises on whether the EWF of micropatches influence the arc spot motion over the cathode surface. Quantitative modeling of the cathode spot is an extremely complex problem. A successful model of the cathode spot requires knowledge of the change in the contact metal's work function. However, since there are several thousands of microsites with different work functions, one must precise that the EWF value measured is the EWF average of the whole contact surface. Although no microscopic EWF values are available, it seems to be reasonable to use the relevant results from photoelectric work function measurements for macroscopic solid surfaces, i.e. developed electrode materials such as Ag–Ni (60/40), Ag–Ni (70/30) and Ag–W (50/50), under UHV conditions. Then, the effects of vacuum outgassing on EWF for these multilayered materials have been reliably investigated for both fundamental and industrial applications.

From the industrial point of view, the switching devices are an important component in the generation, transportation and distribution of electrical energy. Given the continuing increase in demand for energy, the economic importance of this topic is very important, it affects the equipment and the safety of electrical distribution network. Therefore, the improvement of this type of equipment, based on the study of the electric arc, has considerable economic and social effects. At long-term, future developments include: the total replacement of SF6-based appliances and equipment with elements in the vacuum in the field of medium and high voltage, the development of devices in vacuum for DC circuits, the manufacture of current limiting circuit breakers switching in vacuum. Therefore, the present investigation was performed to contribute to a better understanding of one important aspect inherent in this topic, i.e. the electronic emission of the cathode, precisely the changes of EWF of contact materials versus surface cleaning treatments by vacuum outgassing.

Electron Work Function (EWF) is one of the important properties of solid surfaces. Usually the EWF of the metal/alloy depends not only on the nature of the metal/alloy but also on its surface condition. Valence electrons are confined to the surface of metals by the dipole layer constituting the surface potential barrier. Electron Work Function is the minimum energy (usually measured in electron volts) required to extract an electron from the surface of a metal at 0 K. The variation in EWF with alloy composition has important implications in electronic emission of silver alloyed contacts. Moreover, the EWF of metals and binary alloys reflects the structure of the surface and the chemical composition in micro- or nano-scale. Changes in EWF due to the adsorption of atoms on metal surfaces have been extensively studied [14].

Since a full-blown theory of the EWF is lacking today, the EWF is usually determined experimentally. Our investigation deals mainly with photoelectric determination of EWF for silver alloys electrical contacts upon vacuum surface treatments, using Fowler's method of isothermal curves [15]. A detailed description of experimental set-up has been given elsewhere [16–19]. All the measurements were carried out in equipment of our own construction, in which a residual gas pressure of 10^{-9} mbar could be obtained using an ionic pump [18,19]. The developed and used experimental method is based on measuring photoelectric currents, emitted by a small electrode exposed to ultraviolet radiations of different wavelengths and same intensity, in ultra high vacuum conditions. The monochromatic UV radiations with the following wavelengths: 196.0 nm, 206.1 nm, 213.1 nm, 223.4 nm, 229.1 nm, 247.8 nm, and 255.4 nm, are obtained with the use of a Hamamatsu Deuterium Lamp and seven interferential filters with a passing band of 10 nm at the half of maximum transmission. Photocurrent measurements (of order of 10^{-12} A) are carried out with a Keithley picoammeter (number 466). An electromagnetic screening has been used to make stable the measurement of photoelectric current; as it stops radiofrequency waves, external electrostatic field and so on.

In this paper, new experiments performed with silver alloys Ag–Ni (70/30) are highlighted. The numbers between brackets represent the massic proportion of pure silver and pure nickel. The cathodes studied are made of alloys Ag–Ni (70/30), Ag–Ni (60/40) and Ag–W (50/50). They are cylindrical, 8 mm in diameter and 3.5 mm in height, with a curvature radius of 16 mm. Before being introduced in the UHV chamber, the electrode contacts are polished with silicon carbide paper and then with polishing textile soaked with alumina powder (grain size 0.3 μm and 1 μm) in distilled water. Then, they are cleaned in an ethanol solution inside an ultrasonic tank, rinsed in water and dried by paper textile soaked in acetone. In order to obtain reliably results, the experiments were carried out at low pressures (10^{-7} Pa) measured with a Bayard and Alpert gauge, and for short times (less than half an hour for one run).

2. Experimental method

The experimental method is based on Fowler's theory [15]. Fowler has developed a theory of the energy distribution of electrons, based upon the assumption that the free electrons in a metal obey the Fermi–Dirac statistics. If a metal cathode is illuminated by ultraviolet light of frequency ν, then Fowler's theory of the surface