Possible new mechanism for anode wire aging in gas-filled detectors

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Abstract

Results from an aging investigation of straw-tube set under sustained irradiation by a ^{90}Sr (2 Ci, β-source) are presented. A thorough study of the aging phenomenon for gold-plated tungsten wires with an accumulated charge of 9 C/cm was made. Aging tests were performed with a gas mixture containing Xe, CO_2 and CF_4. As a result of aging, the gold coating on the wires was destroyed, and the wire diameter increased from 35 ìm to 42 ìm. It is shown that this anode swelling effect can be explained by tungsten oxidation on the wire. This is a possible new aging mechanism for anode wires.

Keywords: aging; wire swelling; new mechanism; oxygen.

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1. Introduction

High energy physics detectors proposed for the Large Hadron Collider (LHC) demand a higher performance than what is available from conventional gas detectors [1,2]. These detectors are intended to operate with no service access for several years. The radiation level near the beam of a storage ring collider will result in an integrated charge level of 10÷13 C/cm after about 10 years of operation. This is at least an order of magnitude more than what has been an achieved in previous experiment. It is clear that the new generation of wire chambers will need higher levels of radiation hardness. Thus, the study of aging effects for these new detectors is especially important.

Usually, aging effects are the result of a surface degradation of both the anode and cathode electrodes that occurs in the form of “deposits” [3].

These deposits are generally some forms of polymer or, in certain cases, may be elemental carbon. Another way of wire (or cathode) surface degradation is chemical attack of the wire surface by active species produced in the gas avalanche. This is typical for non-gold plated wires which contains chemically active elements in the wire surface material [4, 5]. The principal explanation for both of these mechanisms can be couched in terms of plasma chemistry. Different types of chemical radicals and positive ions produced in the gas avalanche near the anode wire cause the plasma reactions leading to both the anode wire and cathode deposits. These radicals cover the surface of the chamber electrodes and even create new chemical substance after interaction with the material of the electrodes.

We would like to propose another possible mechanism for the anode wire aging [6] which does not come from space surrounded the anode wire. In this case, damage of the wire surface develops under the gold coating of the wire. This is the principal difference between our proposed new mechanism and others. Of course, the starting point of this effect is the process taking place inside the gas avalanche.

2. Aging results

The most obvious case of the new aging mechanism is from the data of the straw-tube aging with a $\text{Õå}+10\%\text{ÑÎ}_2+20\%\text{CF}_4$ working gas mixture. The aging studies of the straw-tube were performed at PNPI (St. Petersburg) using the Aging Test Station (ATS) [7]. The setup of the aging test at the ATS is presented in Fig. 1. The degradation test of the detector was carried out by using a ^{90}Sr (2Ci) â-source. Measurements of the straw-tube properties were performed regularly after every few days of exposure. When the ^{90}Sr was removed, the dark current and count rate (with and without an X-ray source ^{55}Fe) were recorded. To monitor the gas gain, the peak position of the pulse-height distribution from the ^{55}Fe source was measured. The applied high voltage was chosen, so as to provide a gas gain 3 X 10^4. This caused a reasonable rate of charge accumulation of 0.15 C/cm per day.

The straw-tubes [8] used in our investigations had a diameter of 4 mm. The cathode consisted of 50 ìm carbon coated capton film, anode wire was gold-coated tungsten with a diameter of 35 ìm.

The analysis of the anode surface after aging was performed using scanning electron microscope with X-ray emission (0-10 keV) spectroscopy (SEM/XEM). The SEM/XEM analysis yielded information on the morphology of the wire surface by imaging with the scattered and secondary electrons, and on the atomic composition of the surface materials by X-ray fluorescence spectroscopy.

The results of the SEM/XEM analysis are presented in Fig. 2. They were carried out both at the edge (non-irradiated zone) and in the center (irradiated zone) of the wire. As one can see, the wire surface out of the irradiation zone is smooth and undamaged. In the center of the irradiation zone, the gold coating is broken and the wire diameter has increased by 20% (from 35 μm to 42 μm). This kind of aging damage is obtained at an accumulated charge of Q = 9 C/cm. SEM/XEM analysis of the damaged area of the wire shows the absence of deposits on the surface. However, the opened tungsten surface among the pieces of the gold coating contained a large amount of oxygen. The EDX results obtained from the different points on the wire are presented in Fig. 2.

The absence of deposits in the irradiated area means we cannot explain the increase of the wire diameter in the usual way. Thus, we propose another explanation of the anode wire aging, which is described below.

3. Anode swelling – a new mechanism for anode wire aging

As mentioned above, the gas avalanche causes a plasma environment in which different types of active radicals are created. Analysis of this phenomenon together with data both obtained by us earlier [7, 9, 10] and presented above led us to propose the following new mechanism for anode wire aging.

The electrons move toward the anode wire in the intense electric field and obtain energy sufficient to break the chemical bounds of the gas molecules.

Thus, due to the dissociation of the CO_2 (dissociation energy E_d=5.5eV) and others oxygen-containing molecules (for example, H_2O E_d=5.2eV) around the anode wire, many electronegative species and oxygen ions are produced [11, 12], which then move to the wire surface under an influence of the electric field. The dissociation of the CF_4 also causes many of electronegative species to drift toward the anode. An additional source of oxygen or oxygen-containing molecules is the diffusion of air through the wall of the straw-tube [13]. Then the oxygen and active chemical radicals diffuse through the gold coating of the wire and oxidize the tungsten. This process results, for instance, in production of WO_3, whose density (7.2 g/cm^3) is 2.5 times less than tungsten (19.2 g/cm^3). This causes an increase in the wire volume i.e., the wire swells.

Hence, due to the oxidation of the tungsten, the wire swells. As a consequence, the gold coating is broken by the forces applied from within the wire. Fig. 3 presents the mechanism for the anode wire swelling.

Oxygen and other aggressive radicals easy penetrate through the open cracks in the gold layer and react directly with the tungsten. As a result, the oxidizing process of the tungsten is speeded up.

Oxygen penetration through the gold to the tungsten is quite possible for the following reasons. First, the gold coating has a crystallite structure [14] whose fragility depends critically on the coating technology used in the wire manufacturing. Second, the oxygen is well dissolved in the hard gold, especially in the areas were the avalanche discharges (streamer or spark discharges are very good for) cause local surface heating. It is well known that the amount of dissolved oxygen in liquid gold does not exceed 20% of the volume. But at a temperature of 450^o C hard gold can absorb up to 48 volumes of oxygen [15,16]. Third, the irradiation of metallic films (gold layer, for instance) provokes the creation of pores [17].

Thus, the starting pores in the gold crystallite structure, which could increase and develop under the influence of sustained irradiation, can result in favorable conditions for the oxygen's and even for more complicated chemical radical's penetration to the tungsten. That the gold layer could have quite porous structure one can see in Fig. 4 where a SEM micrograph of the irradiated anode wire surface is shown.

4. Conclusion

We have shown that under a high irradiation dose (9 C/cm) we could observe a new aging mechanism for anode wires – the swelling of the wire. This phenomenon can be explained by the tungsten oxidation. The principal difference between this proposed mechanism and others is that the forces causing the damage to the wire surface develop under the gold coating of the wire.

Furthermore, we have found that atomic oxygen plays a very important role in this anode wire aging process and greatly speeds up the aging of anode wires under a high irradiation dose.

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Fig. 3. Mechanism of the anode sweling effect. A schematic view of an anode wire cross-section is shown before (Fig. 3a) and after (Fig. 3b) irradiation.

Fig. 4. SEM micrograph of the anode wire surface in the center of the irriated zone – see Fig.2 (Zone 1). The (5 µm length) is is indicated as a white line on the top part of picture.

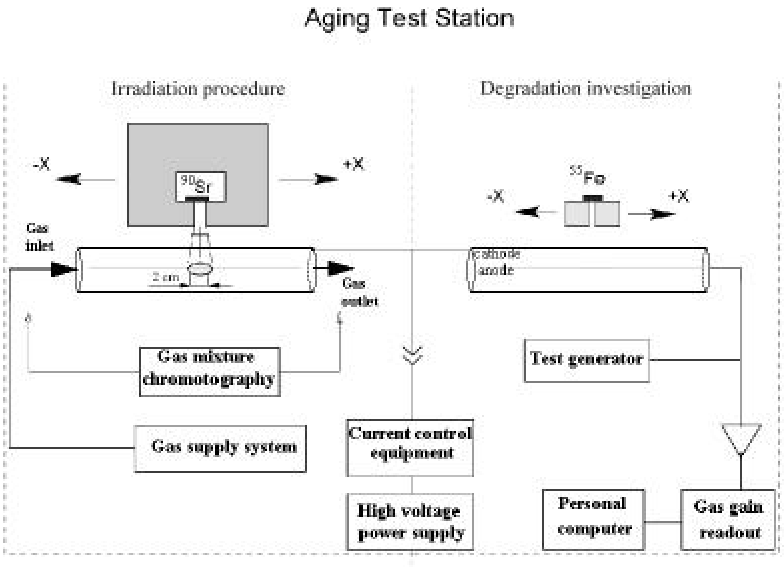
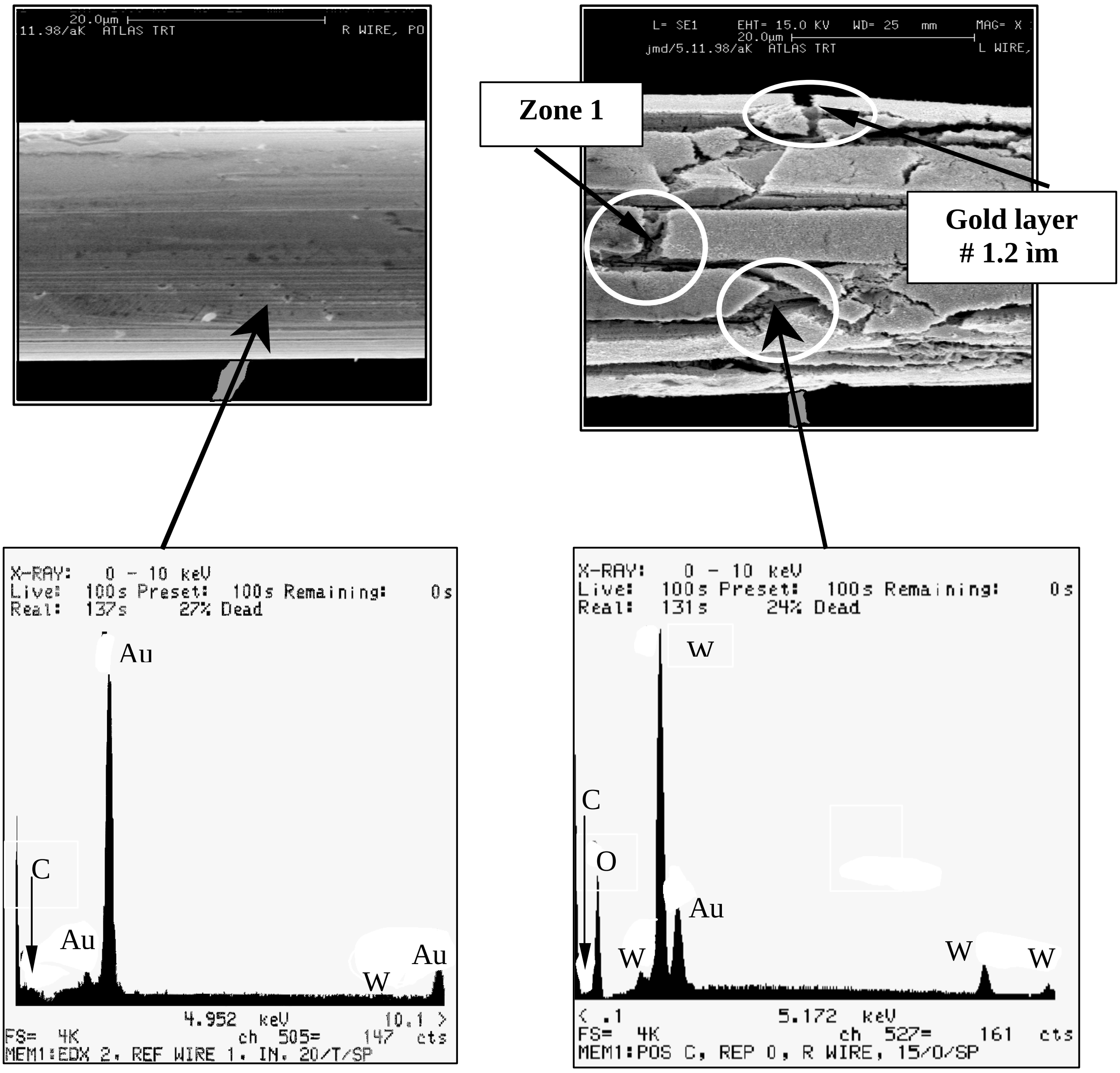


Fig. 1. Diagram of the Aging Test Station (ATS) in Gatchina.

Fig.2a. Edge of the wire. Non-irradiated zone. Diameter - **35 µ*m.***

Fig.2b. Center of the wire. Irradiated zone. Diameter - **42 µ*m.***



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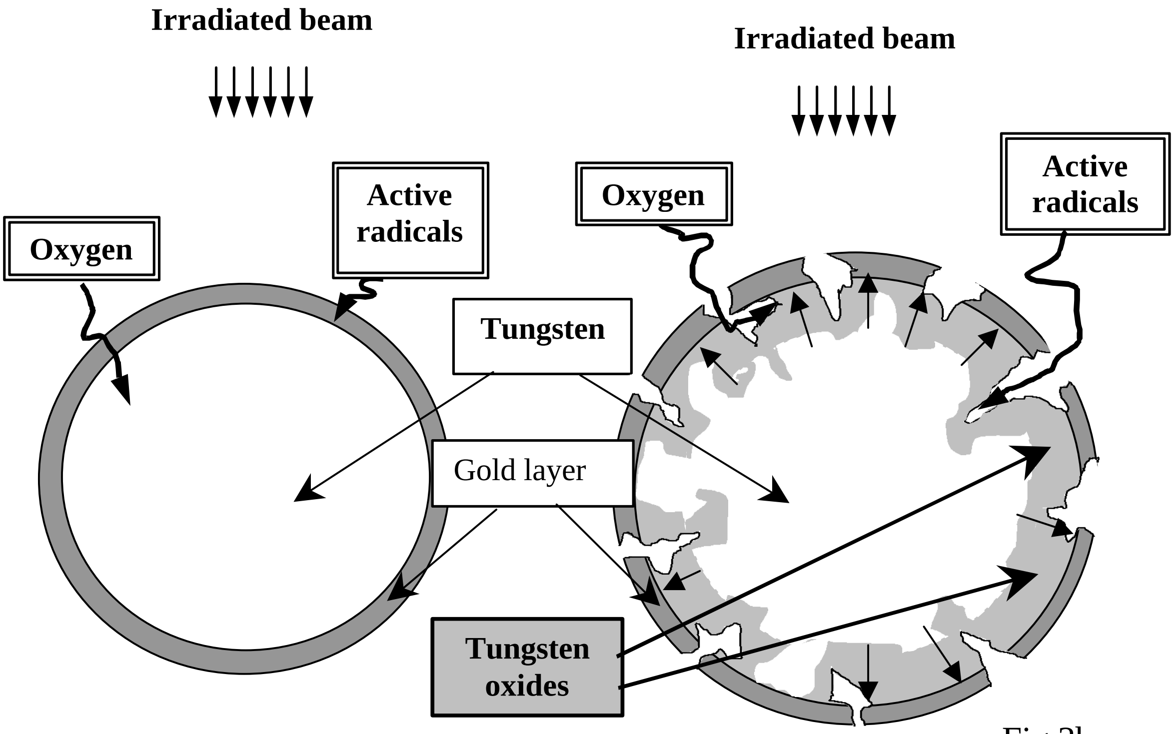

Fig.3a

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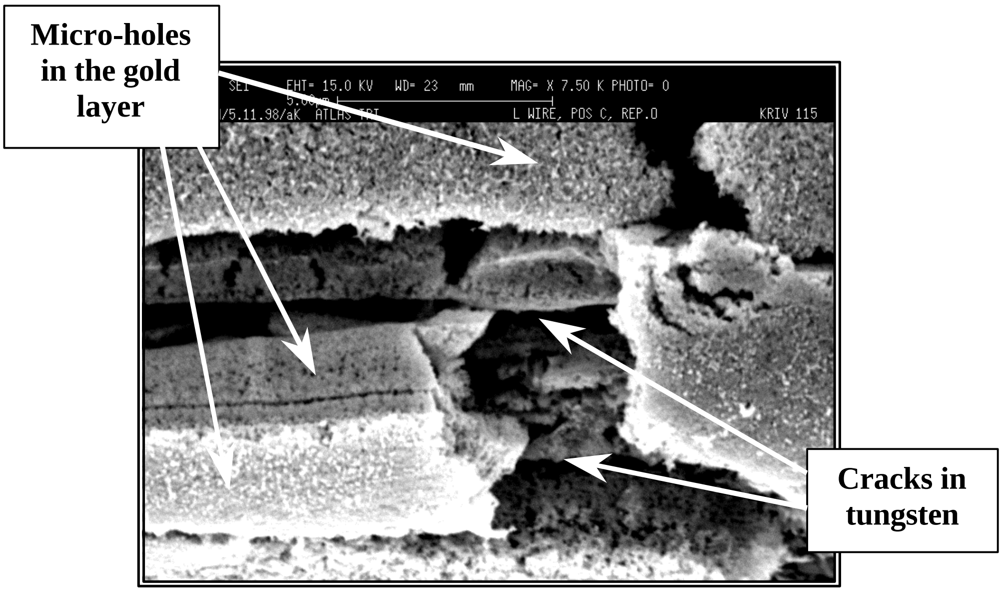

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