NONINVASIVE METHOD OF RECOVERY OF GAS PARTICLE DETECTORS UNDER OPERATION IN HIGH-INTENSITY FIELDS OF RADIATION

V.A. Andreev, G.E. Gavrilov, A.G. Krivshich, D.A. Maisuzenko, A.A. Fetisov, N.Yu. Shvetsova

1. Introduction

Here we describe a method of noninvasive recovery of gas-discharge detectors, which have been degraded due to operation in intense radiation fields. The proposed techniques are based on the plasma-chemical reactions, which occur during the detector training in the gas discharge that is generated in a special gas mixture. It has been shown that the method of plasma-chemical etching in a gas discharge increases the detector lifetime in several times.

Usually, aging effects result in a surface degradation of both the anode and cathode electrodes, which occur in different forms. The first one is the anode type of aging. First of all, it is associated with silicon deposits formed on the surface of the anode wires. The source of these deposits are structural materials and elements of the gas supply system of the detector [1]. These effects are manifested even with small accumulated charges in the range of 0.1–1.0 C/cm of the anode wire length. If there would be no silicon contamination in the detector, it could operate at higher doses with the accumulated charge exceeding 1 C/cm. In that case, the main mechanism of aging would be swelling of the wire caused by chemical interaction of the oxygen which is coming from the gas avalanche with the tungsten which is the main material of the anode wire [2].

The second type of aging is the cathode aging. It is associated with formation of dielectric films at the cathode, which usually cause the Malter effect (ME) [3, 4] – spontaneous self-sustained current in the detector initiated by electron emission from the cathode surface through dielectric films formed at the cathode.

The explanations of these mechanisms can be considered in terms of plasma chemistry. Different types of chemical radicals and ions are produced in the gas avalanche near the anode wire. They can cause plasma chemical reactions. Polymers and other chemical compounds resulting from these reactions may deposit on the surface of the detector electrodes and due to interaction with the electrode materials may form even new chemically different substances.

A noninvasive method of cleaning the cathode and anode wire surface from organic compounds, silicon, and tungsten compositions (swelling effects) has been developed at PNPI. It is based on the plasma-chemical etching reactions which are used in the microelectronics production. Recovery of the main technical characteristics of the detector after its aging without disassembling and repairing is actual for many physical experiments, since the development of a detector operating with an accumulated charge of about 10–20 C/cm is still a problem.

2. Malter effect at the cathode

For recovery of multiwire proportional chambers (MWPC) of the muon tracker in the LHCb experiment at the Large Hadron Collider from the ME, the 40% Ar + 55% CO_2 + 5% CF_4 working gas mixture with added 2% of oxygen was tested. The oxygen radicals and ozone produced in the gas discharge plasma near the wire interact efficiently with organic and silicon films at the cathode, forming volatile compounds, which are removed in the process of gas flushing [5, 6]. Figure 1 shows the Malter current as a function of MWPC training time. The ME current on a level of 25 μA was ignited by ^{90}Sr β-source irradiation at a voltage of 2 600–2 700 V and maintained by increasing the voltage step by step up to the maximum value 2 850 V; the ME current decreases as the formations at the cathode are removed. As one can see, during four hours of MWPC training in the gas mixture with 2% oxygen, the ME nearly vanished. In contradictory to this, the current remained virtually constant even after six hours of MWPC training in the working gas mixture. This method was used to recover four MWPC units, which could not be recovered by training in the working gas mixture.

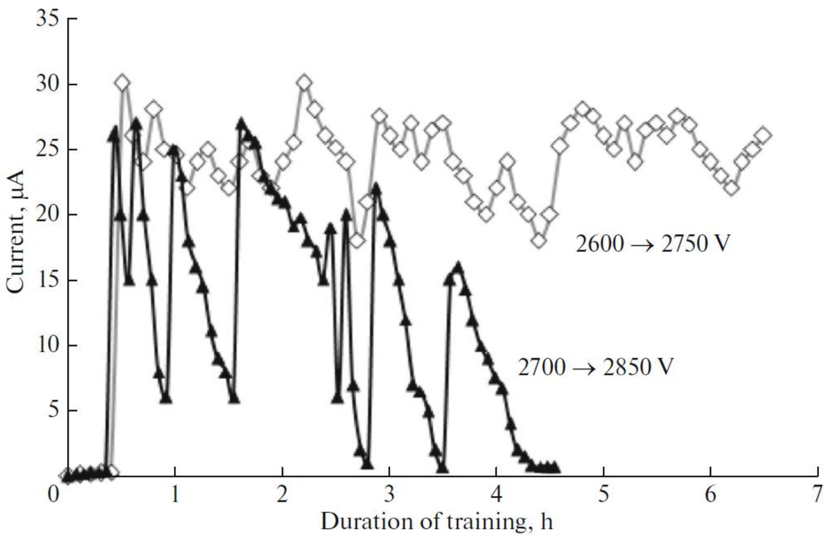

Fig. 1. Malter current in a MWPC during recovery: ◊ – training in the working gas mixture; ▲ – gas mixture with 2% O_2 added

3. Anode wire recovery

The etching of various types of formations on the anode wire surface took place in the gas-discharge plasma that is generated in the 80% CF_4 + 20% CO_2 gas mixture near the anode wire with a negative potential. The basis of the process is the plasma-chemical etching by fluoride active radicals both silicon and tungsten containing compounds in the gas discharge in the vicinity of the anode wire.

In the course of the wire recovery, the damaged region is irradiated by a ^{55}Fe source. *X*-ray photons with an energy of 5.9 keV maintain ionization in the gas-discharge plasma and provide desorption of the etching products [7–9]. The etching efficiency of silicon and tungsten formations was studied with the use of proportional straw counters.

The experimental results of the straw recovery from silicon formations are shown in Fig. 2. The diameter of the anode wire in the straw was 50 μm, the diameter of the cathode-polyamide tube with deposited carbon was 4 mm. The straw aging effects were studied in a gas mixture of 60% Ar + 30% CO_2 + 10% CF_4. This straw was irradiated by a ^{90}Sr β source with a total intensity of about 15 MHz. The anode wire was aged three times in a silicon-contaminated gas mixture until the amplitude was reduced by ~ 35%, and each time the anode wire recovered in the 80% CF_4 + 20% CO_2 gas mixture.

Figure 2a shows the wire surface pictures from the scanning microscope and the *X*-ray fluorescence analysis spectra (SEM/XEM) of the wire surface before and after three "aging–recovery" cycles. As one can see, the wire diameter has increased from 50 to 59 μm (18%). Intensive peaks of silicon and oxygen are observed on the anode wire surface.

Figure 2b shows the gas amplification factor (GAF) behaviour as a function of the accumulated charge. In order to be sure that the recovery effect exists for silicon polluted anode wires, two independent straws were aged and recovered. Each of them was subjected to this procedure three times. The obtained results were very similar (see Figs. 2a and 2b), which confirmed the effectiveness of the proposed method.

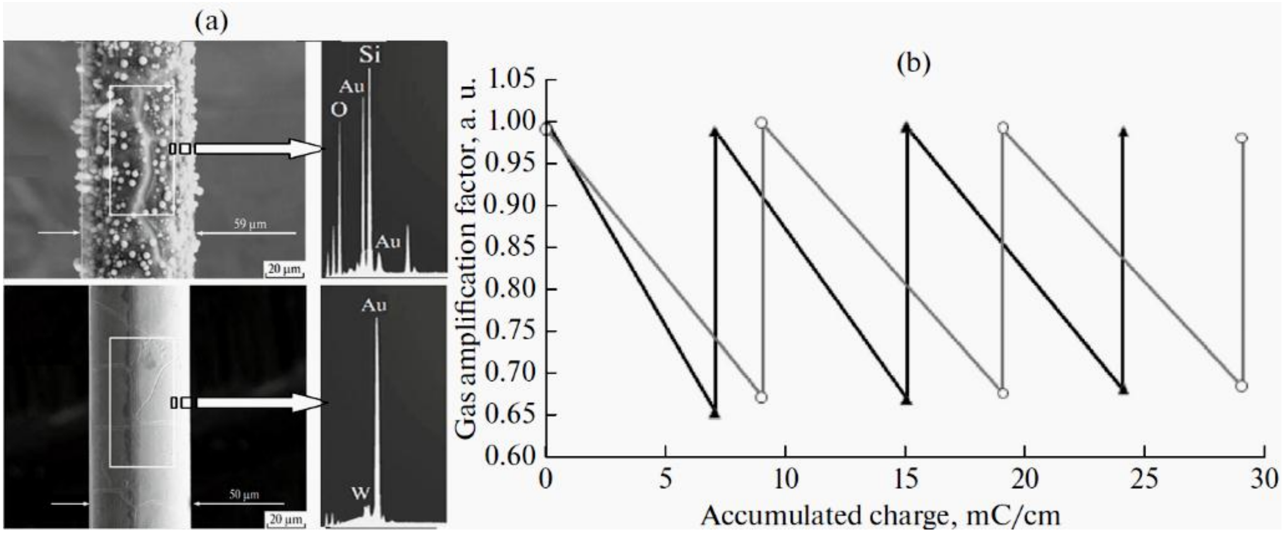

Fig. 2. Results of a SEM/XEM examination of the surface of an aged anode wire (*upper part*) and of a wire recovered by the etching procedure (*lower part*); on the *right side* – results of a XEM spectra analysis of the wire surface are shown (a). GAF as a function of the accumulated charge during multiple recovery of two counters (b): ▲ – straw-1; O – straw-2; *slanting lines* – the GAF reduction during irradiation; *vertical lines* – the GAF recovery during etching

For achieving the anode swelling effect, a clean gas system was used. In order to be sure that the recovery effect exists for swelled anode wires, two independent series of measurements were performed, for each of them the aging-recovery cycles were repeated three times. The obtained results were very similar (Figs. 3a and 3b). In the first series, straws were irradiated until the signal amplitude dropped down by ~ 6%, and in the second series, it dropped down by ~ 3% [10]. The results of measurements are shown in Fig. 3. Figure 3a shows a SEM/XEM analysis of the anode wire surface. A film of tungsten-oxide compound is clearly observed on the gold coating of the wire. Figure 3b shows the GAF behaviour as a function of the accumulated charge.

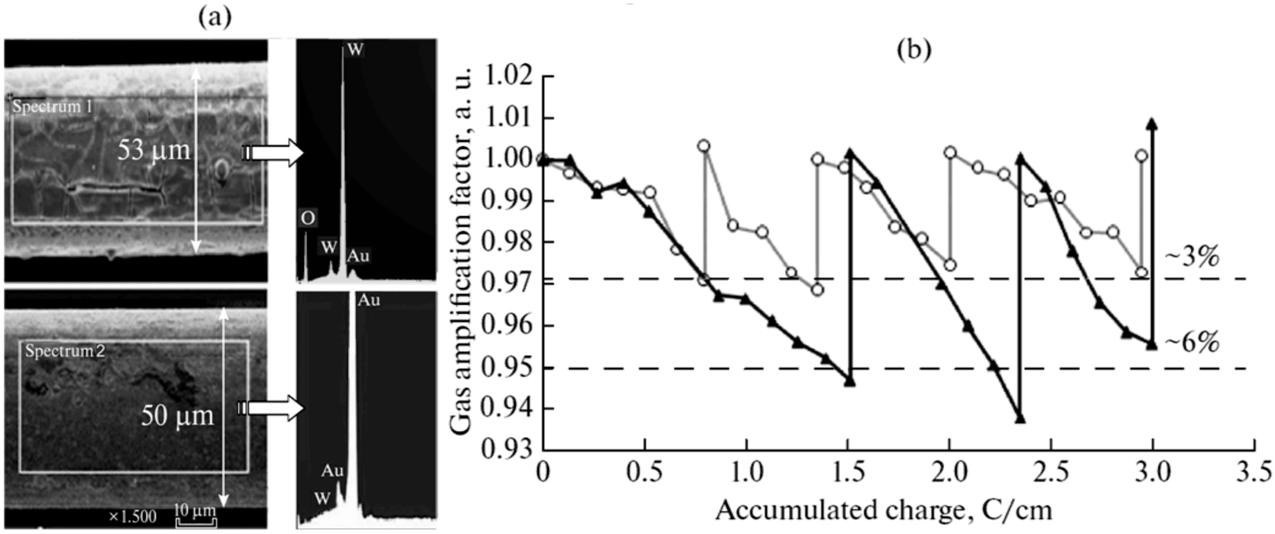

Fig. 3. Results of a SEM/XEM examination of the surface of an aged wire (*upper part*) and of a wire aged and three times cleaned (*lower part*); on the *right side* there are results of a XEM spectra analysis of the wire surface measured in a rectangular area indicated by a white line on the *left side* (a). GAF as a function of the accumulated charge during multiple recovery of counters (b): ▲ – straw-1; ○ – straw-2 [10]

4. Conclusion

Application of the proposed method of the plasma-chemical etching in a gas discharge to recover the aged gas-discharge detectors increases the detector lifetime by several times. This method of recovery has a universal character and can be a suitable solution to the problem of detectors aging in future experiments.

References

1. M. Capeans, Nucl. Instr. Meth. Phys. Res. A **515**, 73 (2003).
2. T. Ferguson, G. Gavrilov, V. Gratchev *et al*., Nucl. Instrum. Meth. Phys. Res. A **515**, 266 (2003).
3. L. Malter, Phys. Rev. **50**, 48 (1936).
4. J. Va'vra, Nucl. Instrum. Meth. Phys. Res. A **515**, 1 (2003).
5. F.I. Grigor'ev, *Plasma-Chemical and Ion-Chemical Etching in Microelectronic Technology, Textbook*, Mosk. Gos. Univ., Elektron. Mat., Moscow, 2003 [in Russian].
6. A.M. Boyarsky, Nucl. Instrum. Meth. Phys. Res. A **604**, 573 (2009).
7. V.P. Zhuze, B.V. Kurchatov, Physik. Z. Sowjetunion **2**, 453 (1932).
8. S. Belostotski, S. Frullani *et al*., Nucl. Instrum. Meth. Phys. Res. A **591**, 353 (2008).
9. G.E. Gavrilov, V.M. Vakhtel, A.G. Krivshich *et al.*, Preprint PNPI-2983, Gatchina (2015).
10. G.E. Gavrilov, D.A. Aksenov, R. Conti *et al.*, Nucl. Instrum. Meth. Phys. Res. A **694**, 167 (2012).