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Ageing test results for TRT straw cathodes

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Abstract.
Results of irradiation stability of TRT straws with different types of cathode film are presented. Three test runs with X-ray irradiation of straws were made in different conditions. The collected electrical charge in each run was about or more than 8 C/cm. There was not found any destruction of cathodes in the tests. The analysis of cathode modifications due to irradiation is done.

1 Introduction

The stable detector operation during total period of LHC run is the main condition which should be proved by detector research and test program. The TRT straws have demonstrated high stability with exposition to a fluence of $4 \cdot 10^{14}$ cm^{-2} from fast fast neutrons and $1.7 \cdot 10^{15}$ cm $^{-2}$ from slow neutrons, and to ionizing particle doses of 800 kGy. The integrated charge of 5 C/cm have passed the anode wires without any change in straw properties [1,2].

The detector ageing have been known since early years of proportional counter operation. The straws as the proportional gaseous detector could be influenced by well-known processes in detector operation, leading to different manifestations of ageing. These manifestations could be loss of gas gain or energy resolution, excessive currents, sparking etc. The deterious effects can be caused by coating or other degradation of anode and cathode surface due to polimerization, oxidation or etching processes. It is known that these processes depend both on gas mixture and cathode and anode materials. Review of experimental results on this subject can be found in [3].

The stable straw operation in irradiation fluxes, shown above [1,2], means that main processes, leading to detector deterioration in operation regime, are supressed. Nevertheless, the eleborate tests of materials for straw manufacturing in view of mass production and comparative analysis of different modifications of materials are needed.

To make choice of polyimide film for mass ATLAS TRT straw production the X-ray irradiation of straw prototypes was carried out in Moscow State University. Four types of polyimide films were used to produce straw prototypes. The straws were tested with anode wires of two diameters: 50 μm in first run and 30 μm in second and third irradiation runs. The total collected charge in each run was about 8 C/cm or larger. It is even more than expected collected charge for TRT in ATLAS operation. The doses were collected more intensively in tests compare to expected rate in ATLAS operation. The irradiation of straws was more intensive from one run to another to observe more clear the irradiation effects on cathode films. The irradiation conditions were identical for straws with different cathode materials in each test run.

The films for straw production differ in presense of aluminium layer and properties of protection carbon layer on the polyimide basis. The proportions of carbon abd polyimide were changed in protection layers. All these differences provide different resistivity of straw cathodes. Film parameters for tested straw cathodes are shown in Table 1.

The experimental straw test procedures and experimental set-up description are presented in Section 2. The straw operation test results are shown in Sec.3. The analysis of cathode modifications after irradiation are presented in Sec.4. Summary and conclusions are in Sec.5.

2 Experimental procedure

The schemes of experimental set-up for straw irradiation and monitoring are shown in Fig.1a and 1b, correspondingly. The set-up includes X ray tube with copper cathode, providing everage gamma energy 8 keV, for straw irradiation, lead abserber with gap of 1 and 2cm, using in straw irradiation, lead abserber with left, right and central collimators 2 mm length for monitoring amplitude spectra measurements, high voltage supplies (HVS), amplifair (A), QDC and voltmeter (DMM).

The sample of 10 straws with 13 cm length was irradiated in first run. It consisted of two straws of each type of four carbon-polyimide films, listed in Table 1, and two straws with polyimide film, covered by copper. In second and third runs 8 straws with the same carbon-polyimide films were irradiated and one straw was running without irradiation for general test monitoring.

In first run the current through each straw wire was chosen to be 5 μA and the length of irradiated zone in the middle of straw was 2 cm. Gas gain was measured to be $2.5 \cdot 10^4$. The streamer probability was estimated as negligibly small. These gas gain value is planning for TRT operation in ATLAS. Gas flow through each straw was 0.25 cm^3/min. The voltages at straws were 1800 V.

In second run the current through each straw wire was chosen to be about 5 μA also, but the length of irradiated zone was 1 cm. It provided twice more intensive irradiation of straws. One of two straws with the same type of cathode film has voltage 1548 V and streamer probability 10^{-3}. Other straw with same type of cathode film operated with 10 times higher streamer probability. The voltage at such straws was 1582 V and the current through these straws was 5.8 μA.

In third run the most hard irradiation conditions for straws were realized. The current though each straw was 15 μA with the length of irradiation zone 1 cm. The voltages on straws provided the streamer probability 10^{-3} with voltagese at straws 1548 V.

Tests parameters for three runs are summerized in Table 2.

The gas mixture was used to be 70% Xe + 20% CF_4 + 10% CO_2, as for straw operation regime in ATLAS. Gas flows in second and third runs were the same as in first one.

The X-ray tube with copper cathode provided irradiation spectra with everage energy 8 keV. The amplitude spectra of K-line of copper was used for monitoring of straw operation. The examples of this spectra with central collimator are shown in Fig.2 before irradiation and in Fig.3 after irradiation with 10 C/cm collected charge. There are no special changes in these spectra, as in any other spectra in all three runs.

For monitoring the amplitude peak position was measured in three regions along the straws: in the middle of irradiated zone (central collimator) and at the distances of 2 cm to the left (left collimator), where gas flowed in, and to the right (right collimator), where gas flowed out the straws. The ratios R_1 and R_2 of the amplitude peak positions in the middle of irradiated zone (R_1) and at the right side of it (R_2) to the amplitude peak position at the left side of irradiated zone, were monitored during the irradiation for each straw. These ratios demonstrated relative gas gain in irradiated (R_1) and not irradiated (R_2) parts of each straw.

3 Test results for straw operation

As it follows from Table 1, the tested films were with or without 2000 Åaluminiun layer and with low or high resistive carbon protection layers on the internal surface of straws.

The relative gas gain in terms of R_1 and R_2 values versus collected charge, passed through the anode wires during X-ray irradiation, is shown in Fig.4(a-d) for straws with different types of cathode film for the first run. Results for films with Al layer are shown in Fig.4a for high resistive carbon layer and in Fig.4b for low resistive carbon layer. There are no ageing effect in gas gain for such straws up to collected charges of 10 C/cm. The same results were obtaned for straws with cathode films without aluminium layer. There was no ageing effect in gas gain for straws with copper covered polyimide film cathode also. The irradiation was stopped at last points, which are presented.

Some interesting observations were made during this test for straw operation in addition to the main results for long term gas gain stability during X-ray irradiation. In Fig.4c the relative gas gain is shown for straw, where gas flow was decreasing after collected charge about 5 C/cm and then was stopped. The gas flow rate for this straw is presented in Fig.4d versus the collected charge. It can be observed that the straw does not show any change in relative gas gain up to collected charge 8 C/cm with decreasing of flow rate and it continued to work even without gas flow during few days. The cathode of this straw was with low resistive carbon layer and without Al.

In Fig.5 the copper K-line peak position is shown in dependence on the atmospheric pressure. It demonstrates the spreading results of gas gain measurements during the first run, caused by this effect, and sensitivity to this effect. The temperature practically did not change during the run. It was stable in limits ±1°C.

The R_1 and R_2 ratios, demonstrated relative gas gain, are shown in Fig.6(a-c) for the straws with 30 μm anode wires in second run with more intensive irradiation. In Fig.6a and 6b results for straws with cathode film with Al and low resistive carbon layers are presented for operation regimes with normal (10^{-3}) and high (10^{-2}) streamer probabilities, correspondingly. The electrical charge was collected up to about 6 C/cm without systematic change in relative gain. Results for straw with cathode film without Al layer and with low resistive carbon layer are presented in Fig.6c for operation with normal streamer probability. There is no losses in ralative gain up to 7 C/cm.

In Fig.7 the streamer probability dependence on high voltage for the straw with 30 μm anode wire, measured in tests, is shown. It confirms the numbers of streamer probabilities shown for different voltages on the straws in second and third irradiated runs.

The relative gas gain behaviour in third run is demonstrated in Fig.8 for the straw with cathode film without Al and with low resistive carbon layer. The extremely large collected charge 18 C/cm was acheived without degradation in relative gas gain in regime with 10^{-3} streamer probability.

4 Cathode modification analysis

The cathode surface after test irradiations did not change visually in first run. In second and third runs the internal surface of cathode film was more lustreless in irradiated regions for films with high resistive carbon protection layer.

The detailed analysis of cathode surface modifications was made with electronic microscope. The samples from second run were analysed more precisely. The selected samples from first and third runs were searched.

The condition of cathodes made from polyimide film with Al and low resistive carbon layer before and after irradiation in second run is shown in Fig.9(a-d). The photographs of the cathode surface with magnification x500 are presented in Fig.9(a,b) and with magnification x5000 in Fig.9(c,d). There are no differences in surface views in protographs before and after irradiation for this film. Results of the element analysis of film surface up to depth of 1 μm before irradiation, after iradiation in second and in third run with larger dose show the presence of carbon, oxygen and aluminium from internal Al layer in same proportions. It means that there are no modifications of film surface due to irradiation up to largest dose 18 C/cm.

The views of cathode surface for the film with Al and high resistive carbon layer are shown in Fig.10(a-d) for the second run. There are more flat sections on the surface before irradiation (Fig.10(a,c)) compare to the view of film surface with low resistive layer (Fig.9(a,c)). The surface of high resistive protection layer has more granuls after irradiation, as it could be seen in Fig.10(d). Results of the element analysis of the film surface demonstrate some changes in proportions of aluminium, oxygen and carbon due to irradiation.

Modification of film surface with high resistive carbon layer is observed in first run also for the softer irradiation regime. It could be seen in photographs in Fig.11(a,b). The condition of film surface before and after irradiation in first run is shown in these figures with magnification x5000. In Fig.11(c,d) the cathode surfaces for film with low (c) and high resistive carbon layer (d) are shown after irradiation in third run at the large multiplication. There are no differences for two types of carbon protection layers after hard irradiation dose. So, the high resistive carbon layer changes under irradiation.

In Fig.12(a,b) the photographs of cathode surface before and after irradiation in second run are presented for film with high resistive carbon layer and without Al. The same modifications after irradiation are observed, as for film with internal aluminium layer. The element analysis of the surface of this film shows the changes in carbon and oxygen relative proportions, as the films with aluminium layers. It means that the presence of Al internal layer does not change the cathode modification under irradiation.

This conclusion is confirmed also by photographs in Fig.13, where the surfaces of the film with low resistive carbon layer and without aluminium layer are presented. Fig.13(a,b) show no surface modifications in second run. In Fig.13(c,d) one can see that in third run of irradiation there are no differences in surface conditions after irradiation for films with low and high resistive carbon layer (both films without Al). The spectra composition of cathode surfaces are very similar before irradiation and after irradiation both in second and in third runs.

The photographs of 30 μm anode wire are shown in Fig 14(a-c) for nonirradiated (a) and the center of irradiated part of the wire for the straw with film without (b) and with (c) Al layer and with low resistive carbon layer in second run as an example.

5 Summary and conclusions.

The experimental tests of ageing properties of straw cathodes were made for different types of polyimide films with monitoring of relative gas gain in irradiated and nonirradiated parts of straws. The films differ in presence of Al internal layer and the resistivity of carbon layer at the surface.

The straws with different films were irradiated by X-ray tube in the same conditions for each run, summarized in Table 2.

The tests show the high stability of films for large irradiated doses with collected charge even more than 10 C/cm, that means much more hard irradiation conditions compare to expected for ATLAS operation at LHC.

It should be noted that the current tests are not sensitive to effect of transient radiation ageing, which was observed in [4-7] for the straw proportional tubes. The time period between the moment when the irradiation was switched off and the moment of the beginning of monitoring measurements, was about 10 minuts as a rule. With gas flow rate and length of the straws, used in the tests, the gas was changed in straws before the monitoring starts. The only object of current tests was to search proterties of cathode materials. The dynamic ageing effect in straw operation should be studies in special experiment.

The careful analysis of cathode surface demonstrates some modifications of high resistive carbon layer on the films. No modifications were observed for low resistive carbon layers after irradiation. These results do not depend on the presence of internal Al layer. The analysis was done by comparison of photographs of surfaces and element compositions on surfaces, made by electronic microscope at CERN.

6 Acknowledgements

It is a pleasure to thank J.-M.Dalin (EST) for the high qualificated work for analysis of irradiation effects with electronic microscope.

References

[1] ATLAS TECHNICAL PROPOSAL, CERN/LHCC/94-43, 1994.

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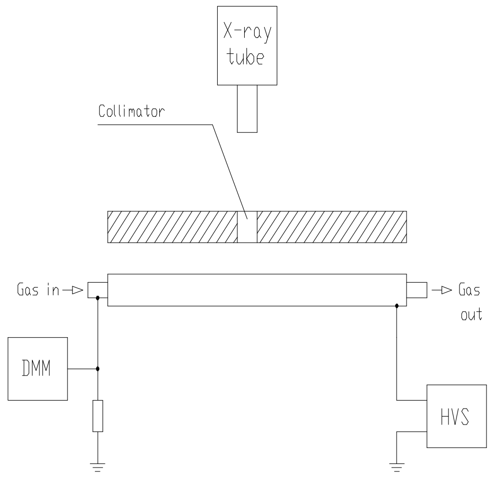


Fig.1a. Set up for straws irradiation.

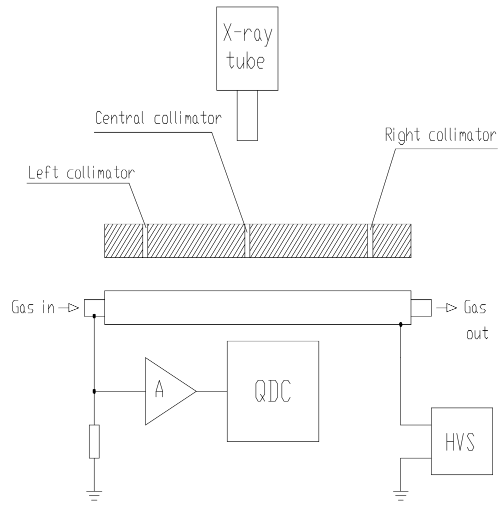


Fig.1b. Set up for straws monitoring.

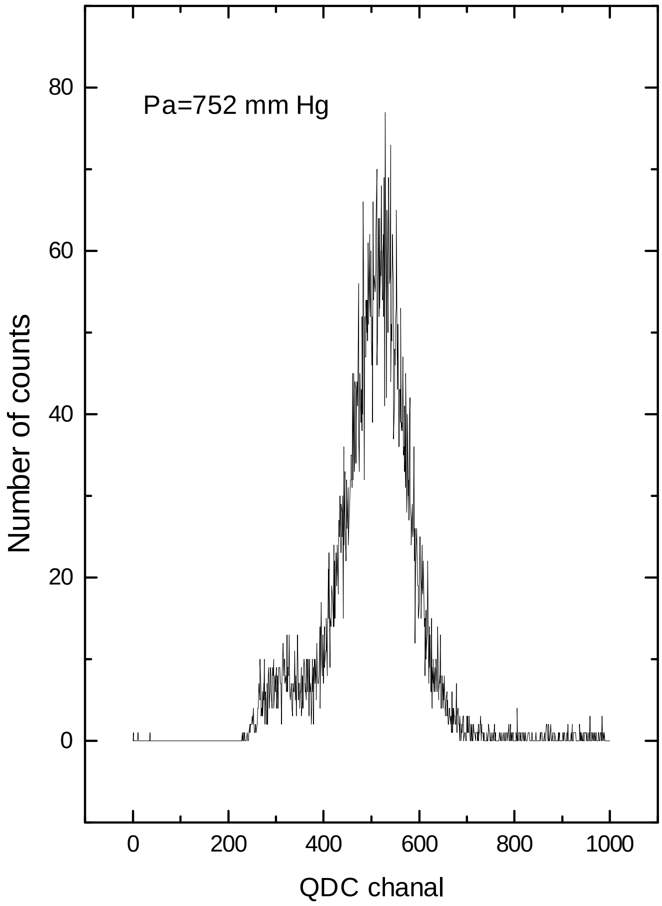


Fig.2. Amplitude spectra from X-ray tube before irradiation.

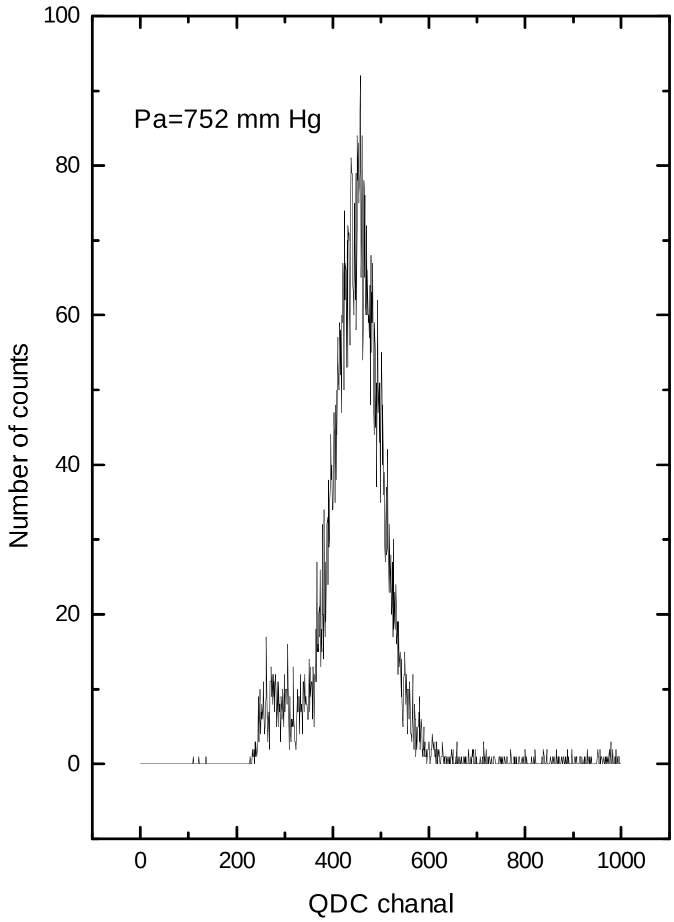


Fig.3. Amplitude spectra from X-ray tube after collected charge 10 C/cm.

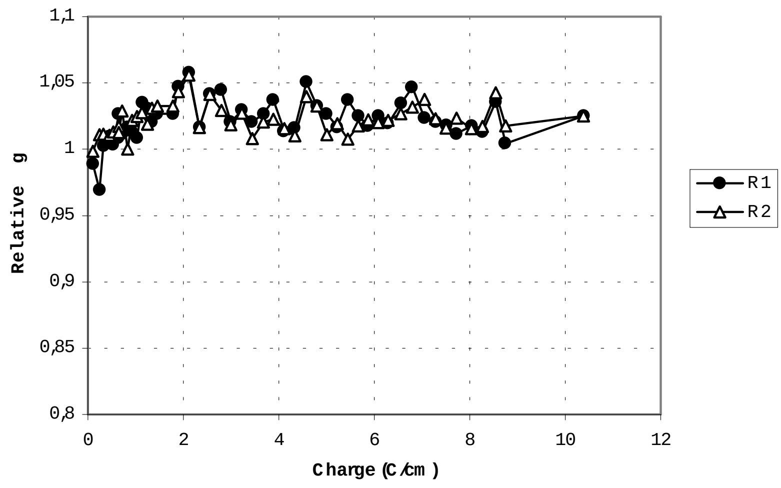


Fig.4a. Dependence of the relative gas gain on integrated charge for tube with high resistive carbon layer and with Al layer.

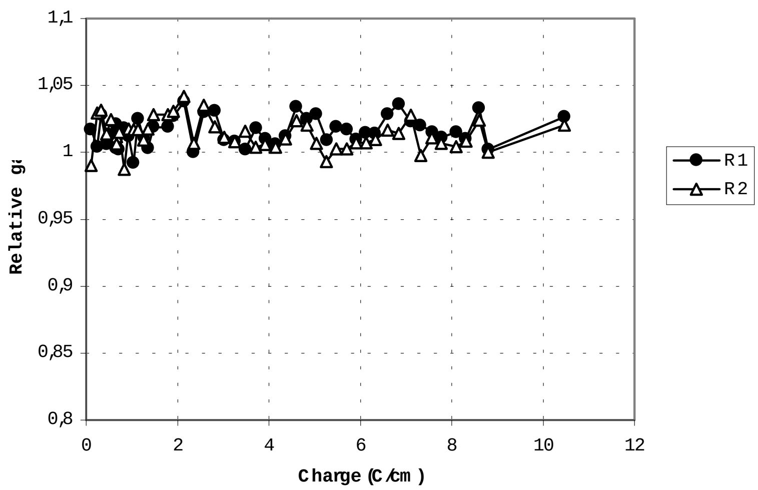


Fig. 4b. Dependence of the relative gas gain on integrated charge for tube with low resistive carbon layer and with Al layer .

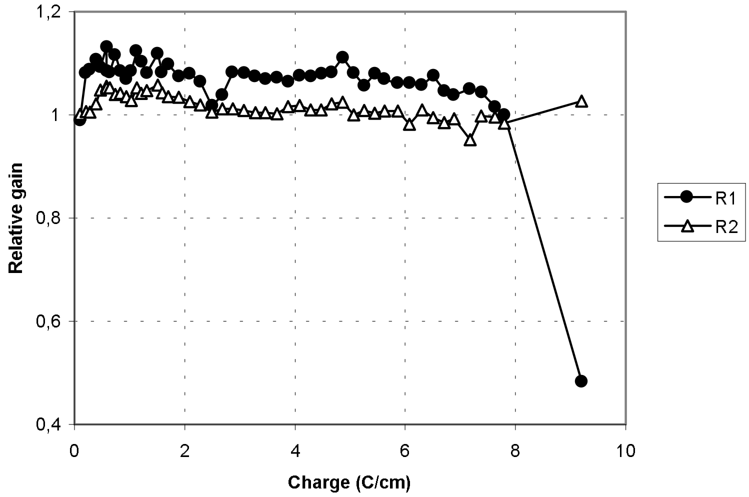


Fig. 4c. Dependence of the relative gas gain on integrated charge for tube with low resistive carbon layer.

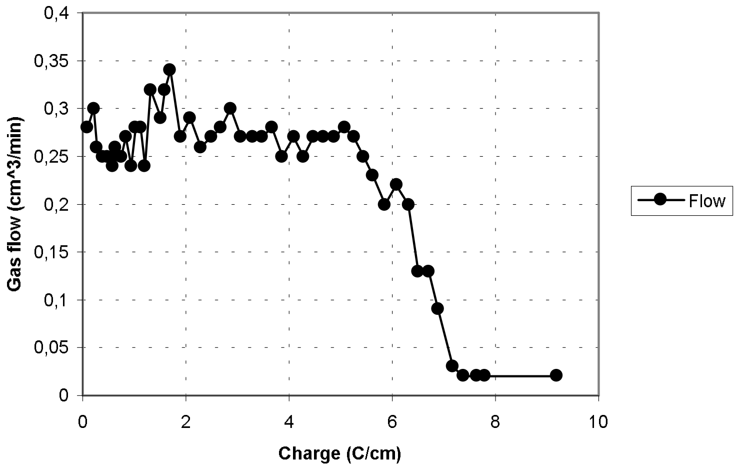


Fig. 4d. Dependence of the gas flow for tube 1 during the run.

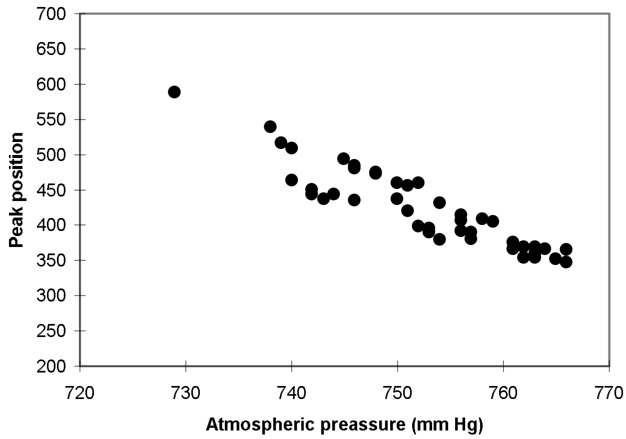


Fig.5. Dependence of the Cu K-line peak position on atmospheric pressure.

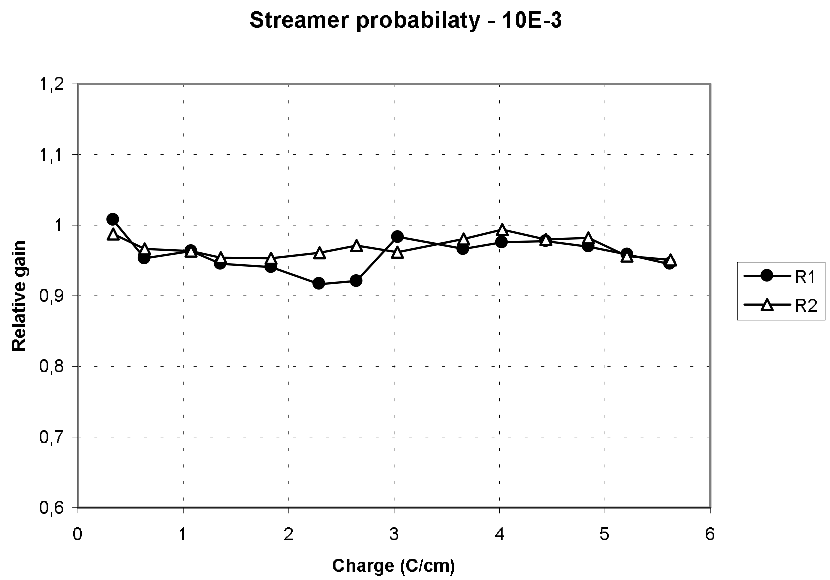


Fig.6a. Dependence of the relative gas gain for tube with low resistive carbon layer and with Al layer for streamer probability 10^{-3}.

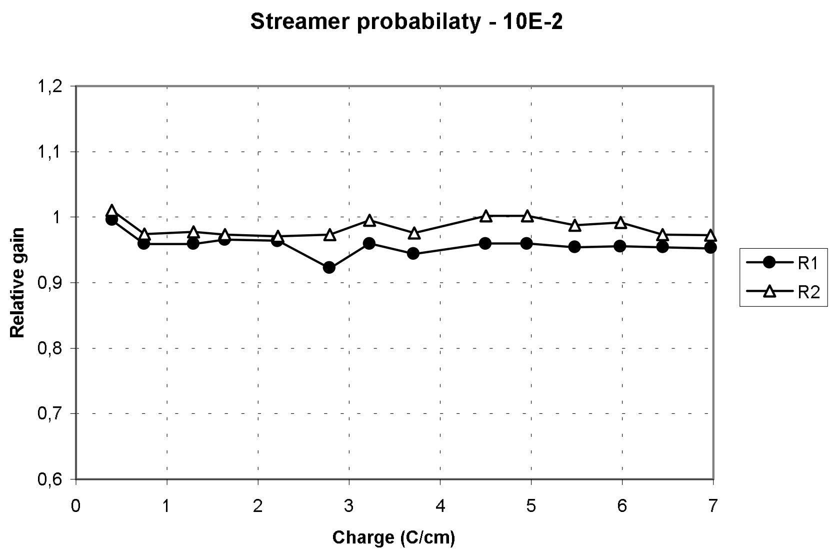


Fig.6b. Dependence of the relative gas gain for tube with low resistive carbon layer and with Al layer for streamer probability 10^{-2}.

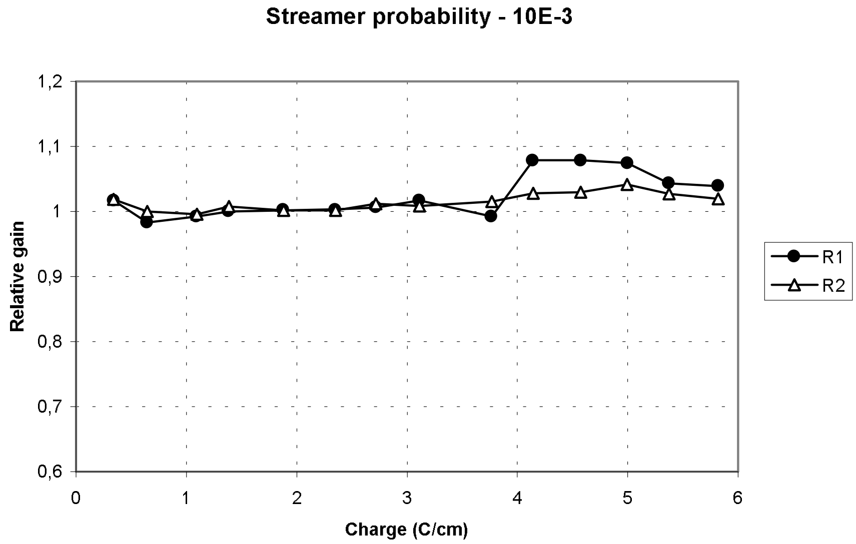


Fig.6c. Dependence of the relative gas gain for tubes with low resistive carbon layer for streamer probability 10^{-3}.

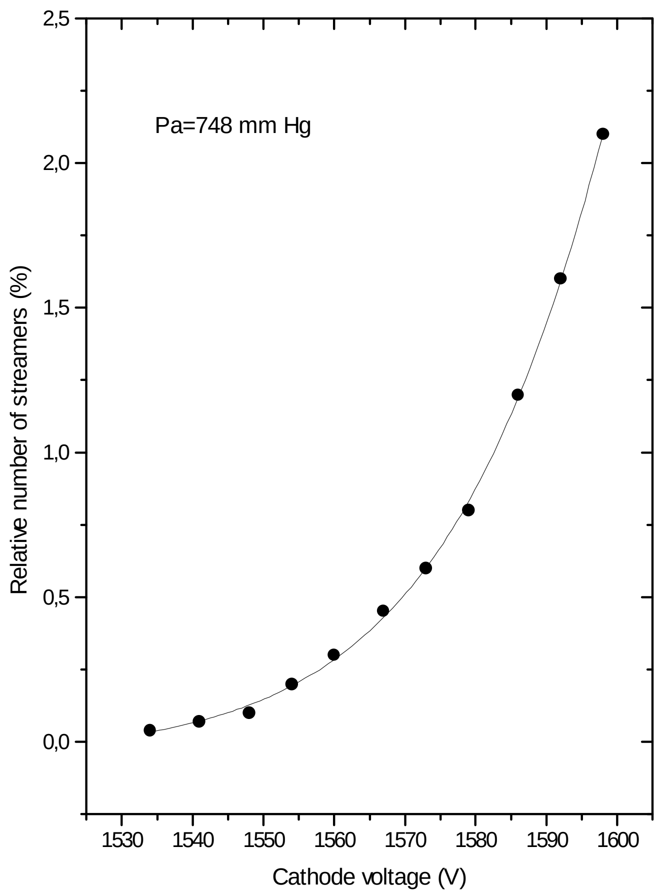


Fig.7. Streamer probability for 4 mm straw tube with 30 μm anode wire.

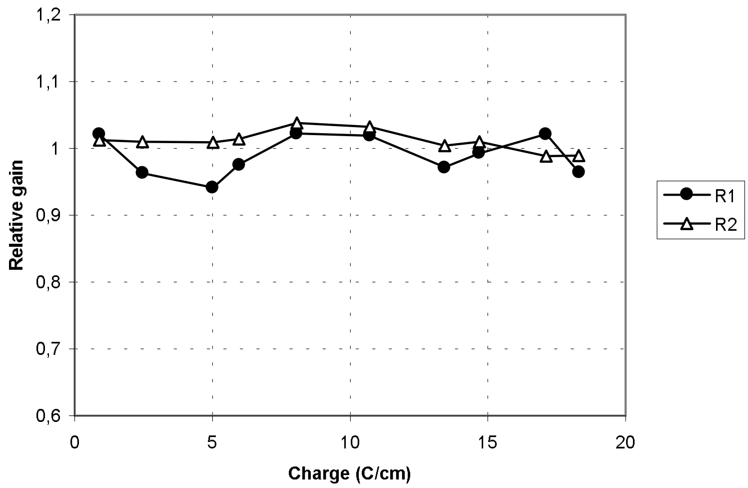


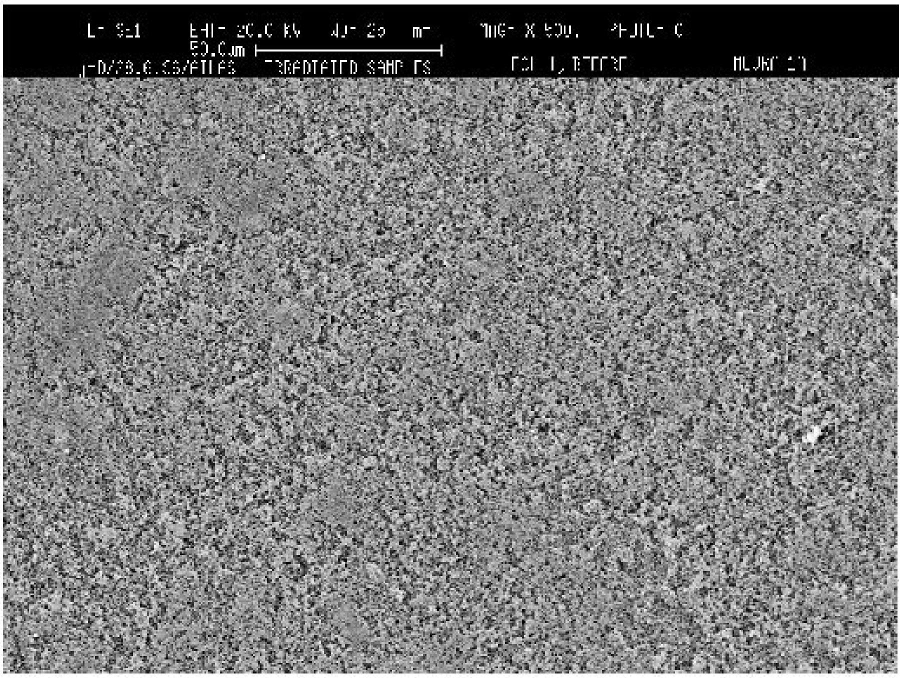
Fig.8. Dependence of the relative gas gain on integrated charge for tube with low resistive carbon layer.

Table 1.

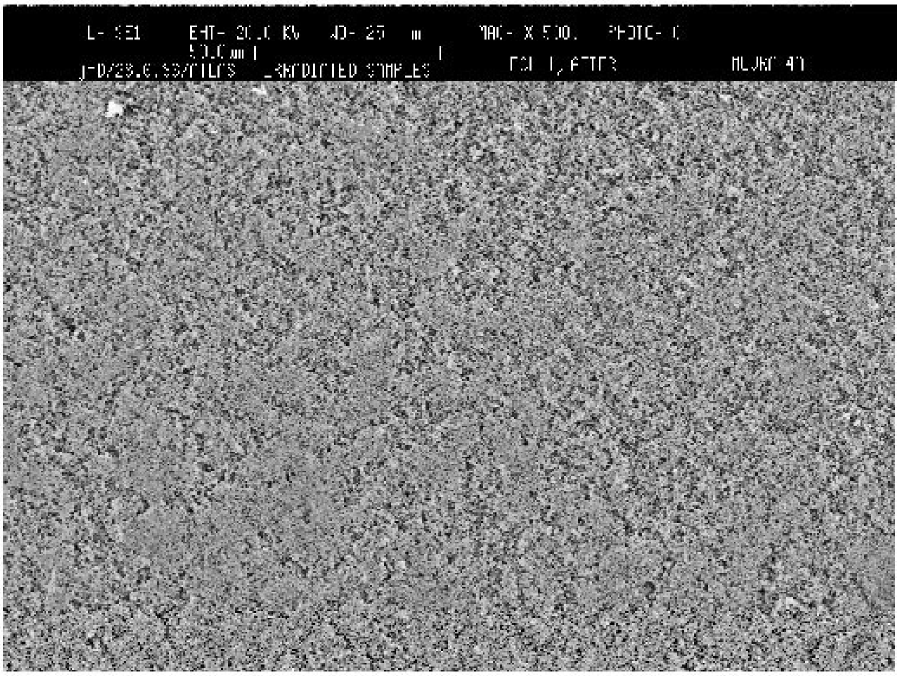
Film Type	External layer resistance (Ohm)	Internal layer resistance (Ohm)
1	70	7,5E+04
2	70	1,1E+06
3	70	110
4	70	70

Table 2

Run	Wire	X-ray energy	Ia	HV irradiat.	Gas gain	Stream. prob.	Gas flow	Straw length	Irrad. zone length
	(μA)	(kEv)	(μA)	(V)		(%)	(cm^3/min)	(cm)	(cm)
1	50	8	2.5	1800	2.5E4		0.25	13	2
2A	30	8	5	1548		0.1	0.25	13	1
2B	30	8	5	1582		1	0.25	13	1
3	30	8	15	1548		0.1	0.25	13	1

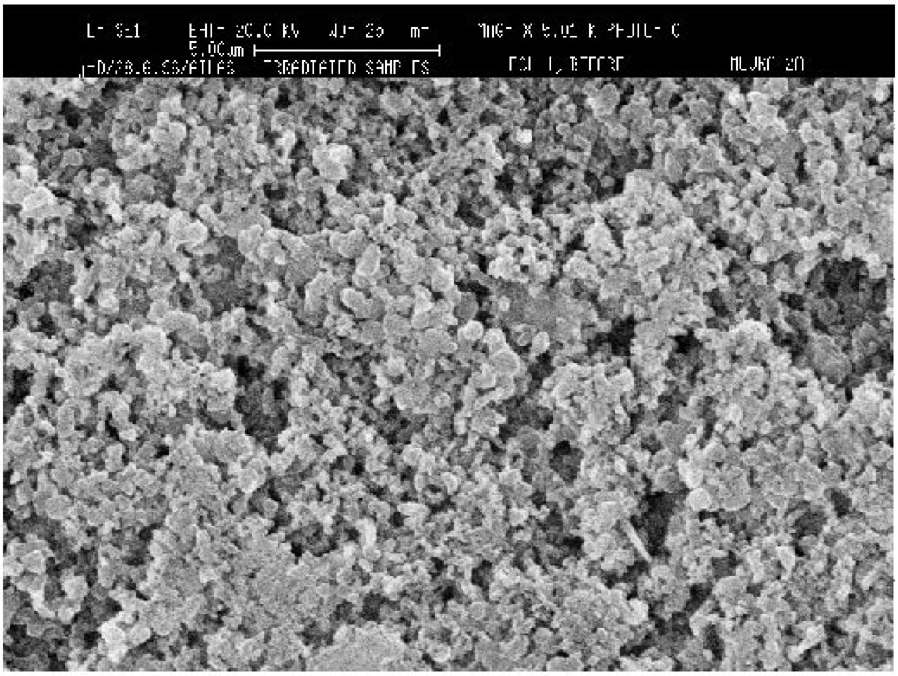


a



b

Fig.9(a,b) Photographs of the surface of the film with low resistive carbon and aluminium layers with magnification x500 before (a) and after irradiation (b) with collected charge 7 C/cm (current density 5 um/cm).



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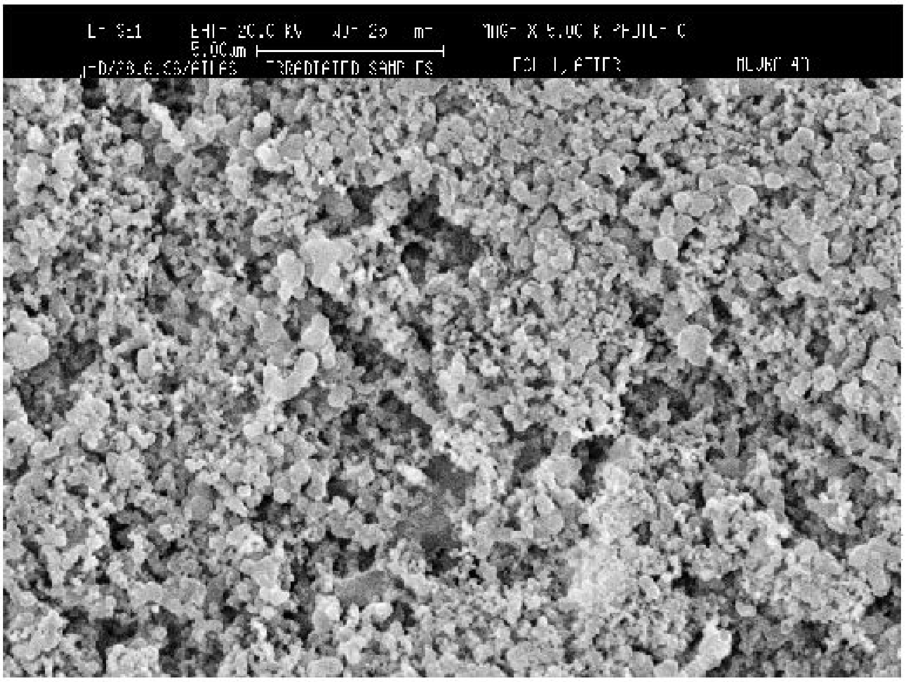
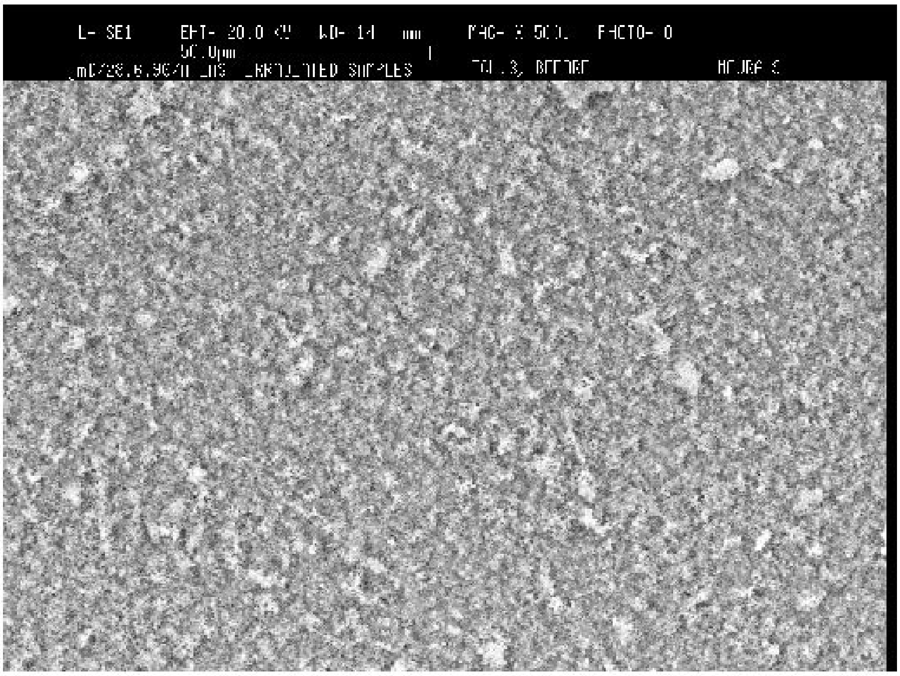


d

Fig.9(c,d) The same as in Fig.9(a,b), but with magnification x5000, before (c) and after irradiation (d).



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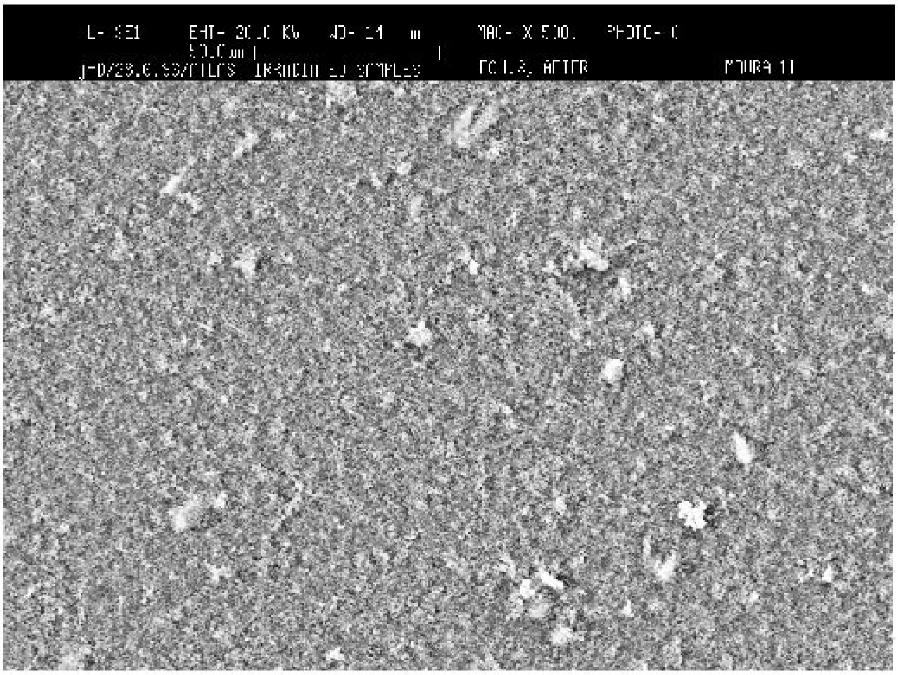
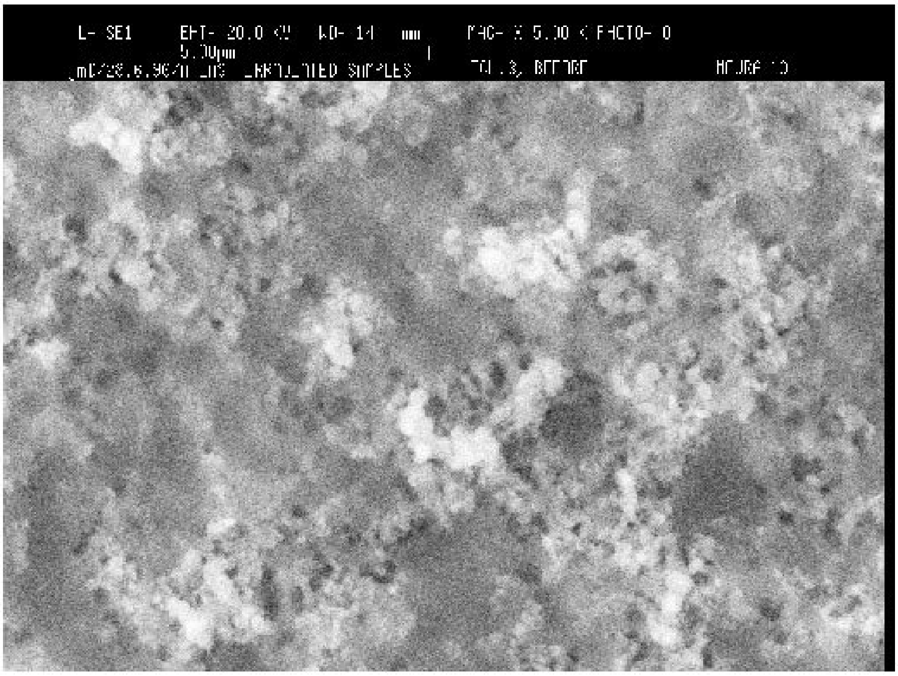


b

Fig.10 (a,b) Photographs of the surface of the film with high resistive carbon and aluminium layers with magnification x500 before (a) and after irradiation (b) with collected charge 6 C/cm (current density 5 um/cm).



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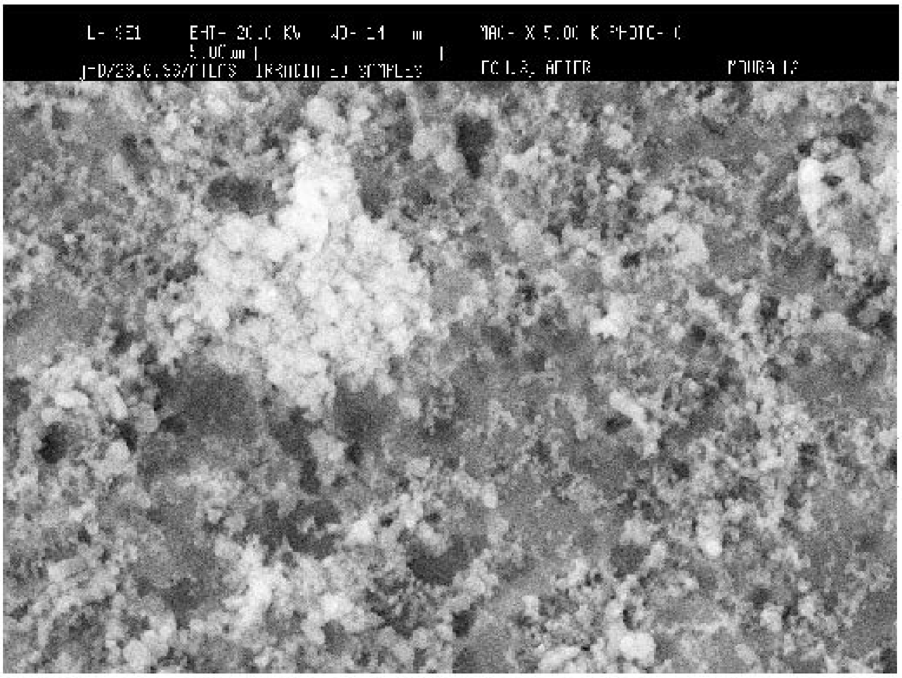

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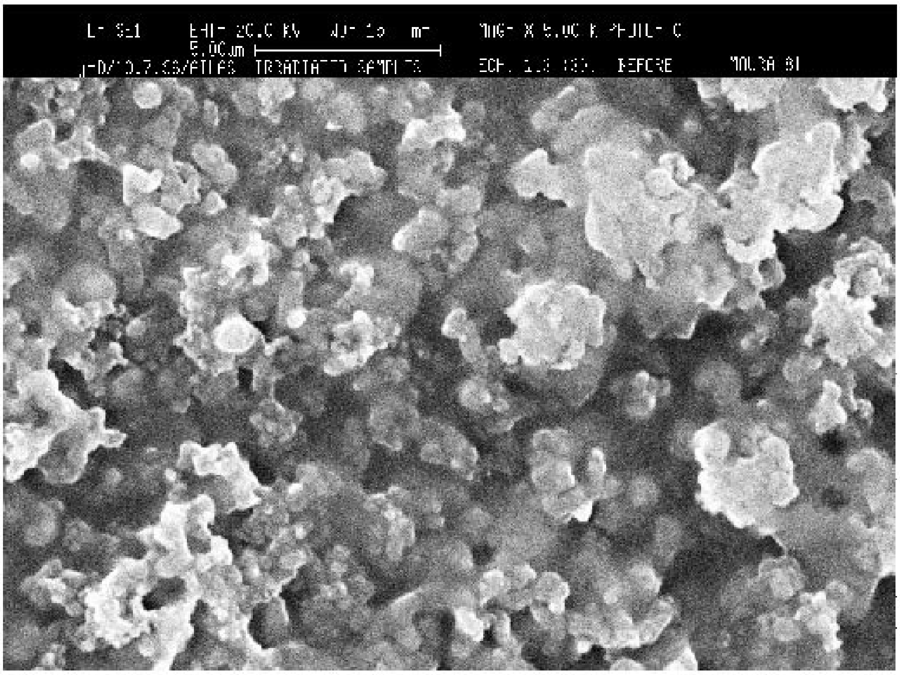
Fig.10(c,d) The same as in Fig.10(a,b), but with magnification x5000, before (c) and after irradiation (d).



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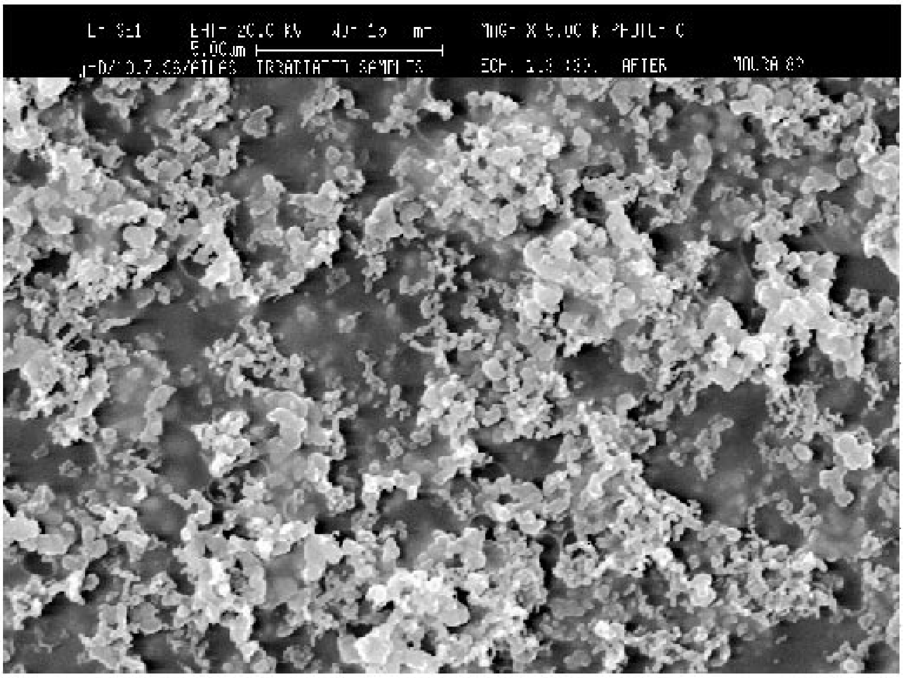
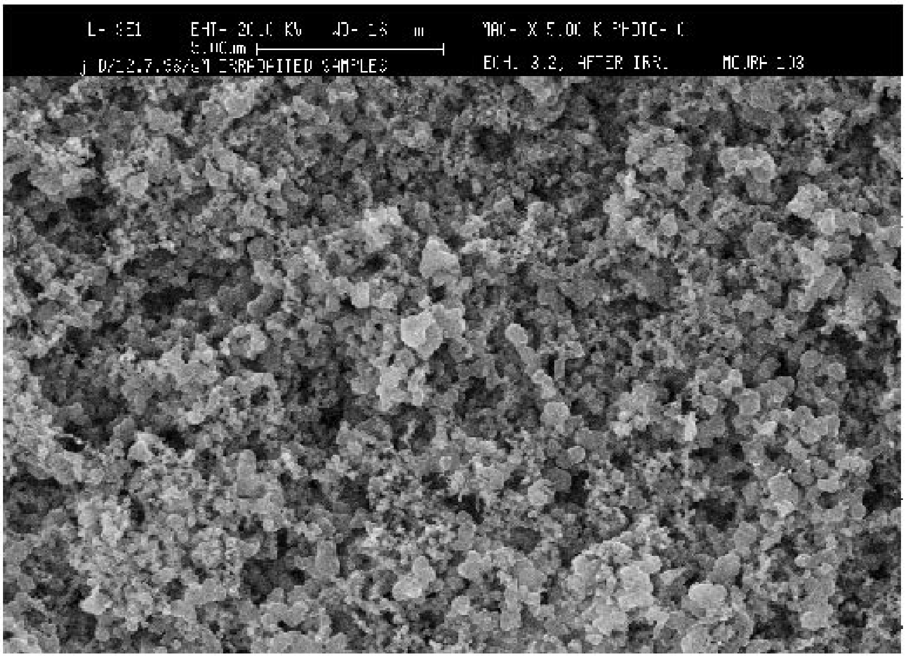


b

Fig.11(a,b) Photographs of the film surface with high resistive carbon and aluminium layers with magnification x5000 before (a) and after irradiation (b) in first run with collected charge 10 C/cm (current density 2.5 um/cm).



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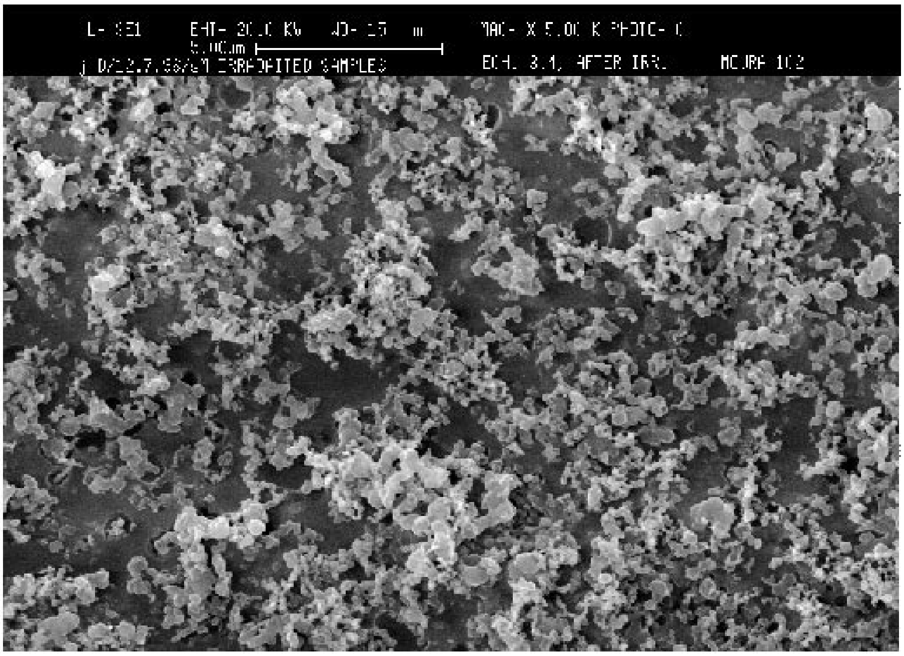
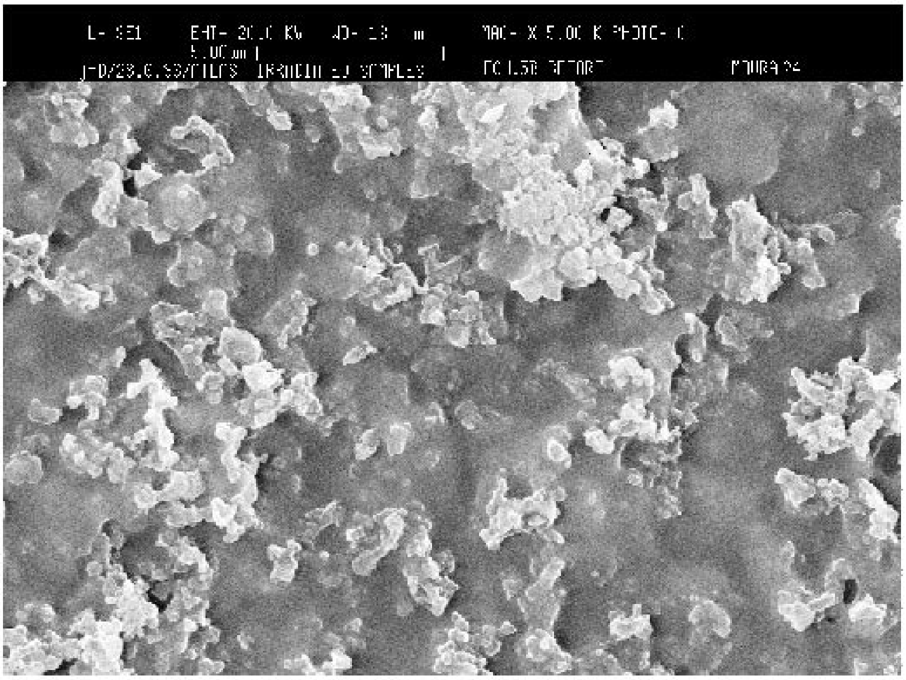


d

Fig.11(c,d) Photographs of the film surface with low resistive (c) and high resistive (d) carbon layers (both with aluminium layers) with magnification x5000 after irradiation in third run with collected charge 18 C/cm (current density 12 um/cm).



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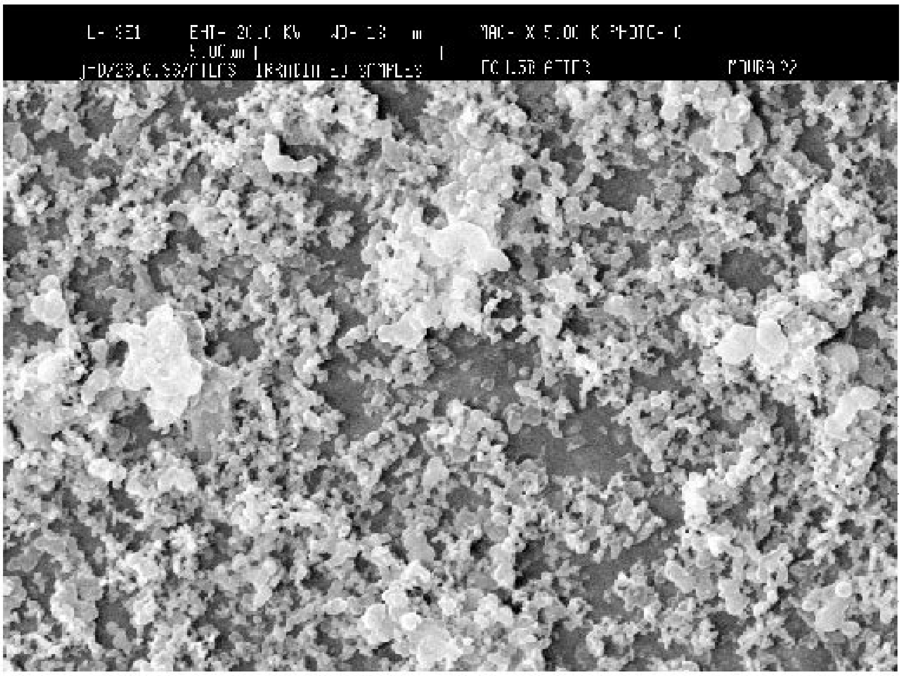
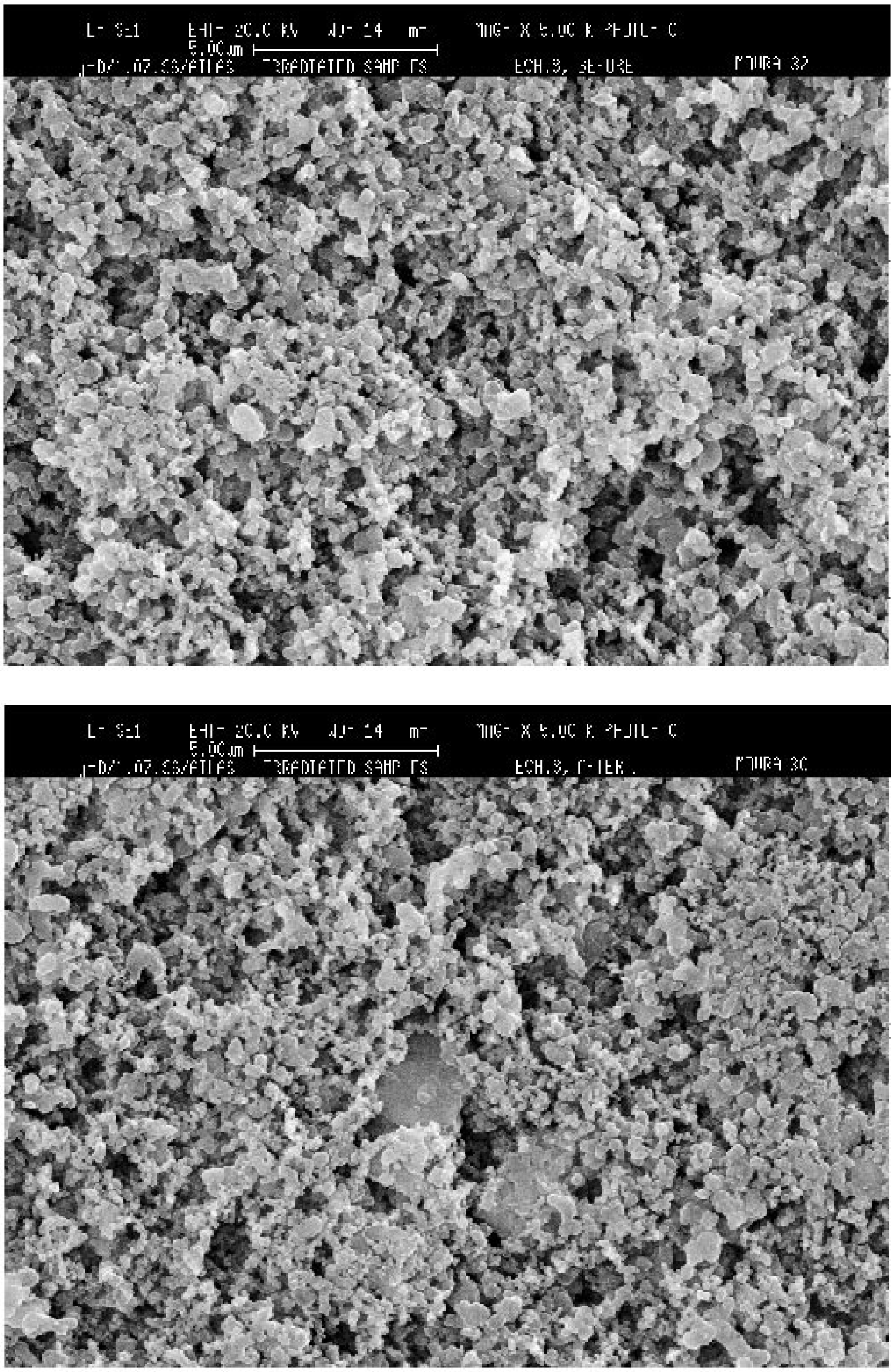


b

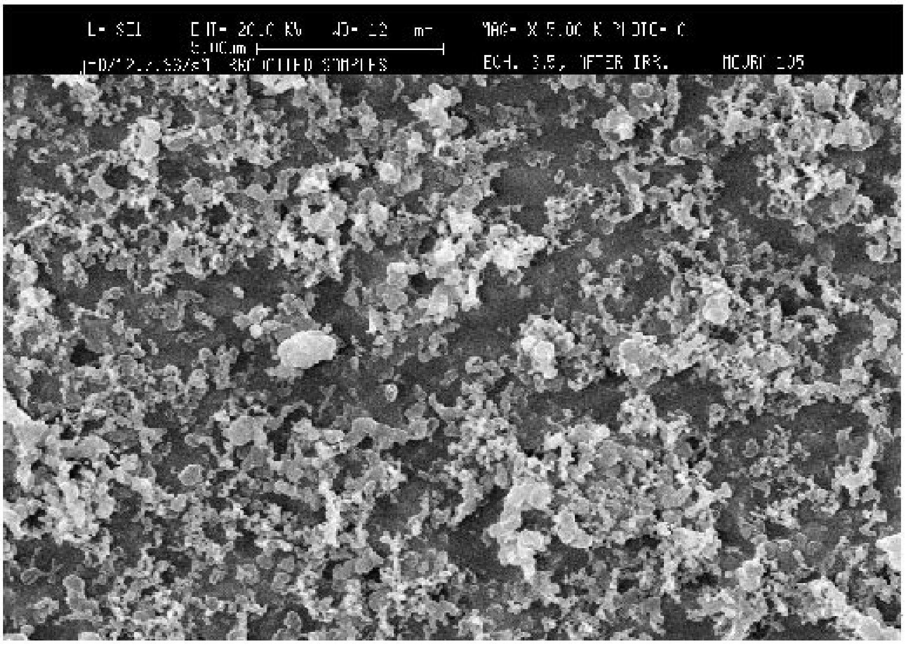
Fig.12(a,b) Photographs of the film surface with high resistive carbon layer and without aluminium layer with magnification x5000 before (a) and after irradiation (b) in second run with collected charge 6 C/cm (current density 5 um/cm).



a

b

Fig.13(a,b) Photographs of the film surface with low resistive carbon layer without aluminium layer with magnification x5000 without irradiation (a) and after irradiation in second run with collected charge 7 C/cm (current density 5 um/cm) (b).



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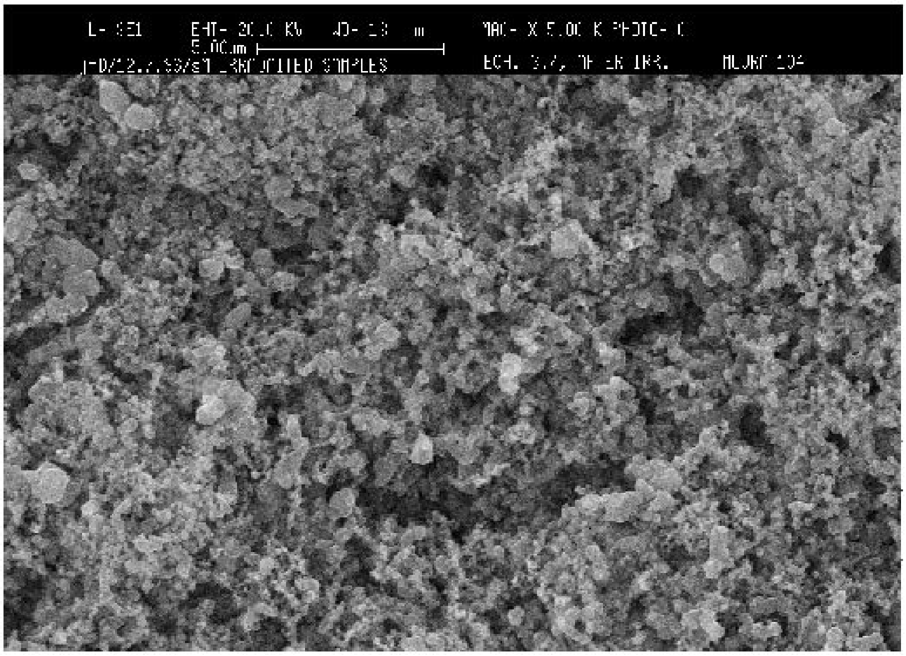
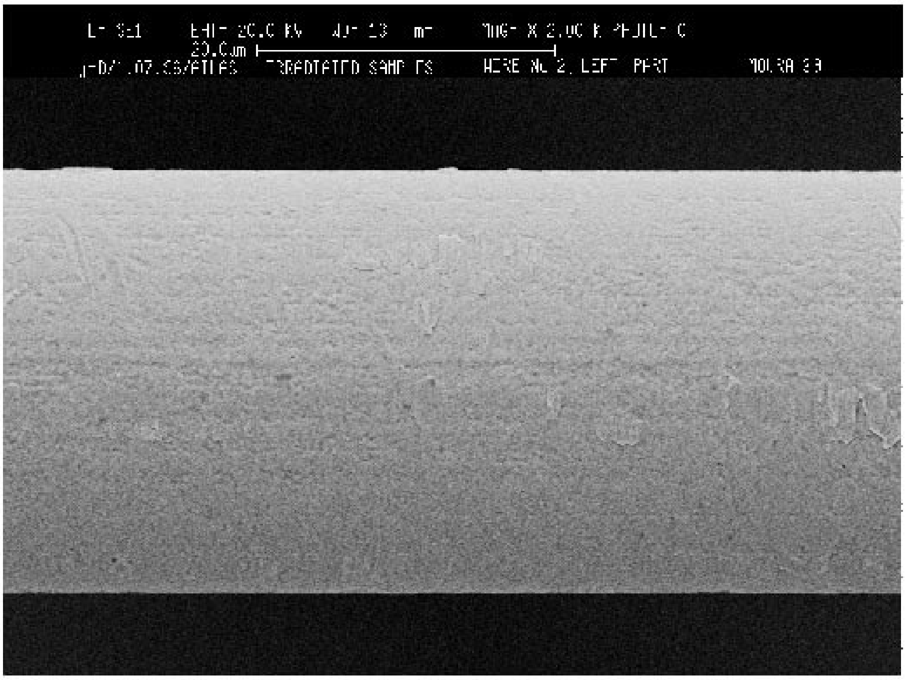


d

Fig.13(c,d) Photographs of the film surface with low resistive (c) and high resistive (d) carbon layers (both without aluminium layers) with magnification x5000 after irradiation in third run with collected charge 18 C/cm (current density 12 um/cm).



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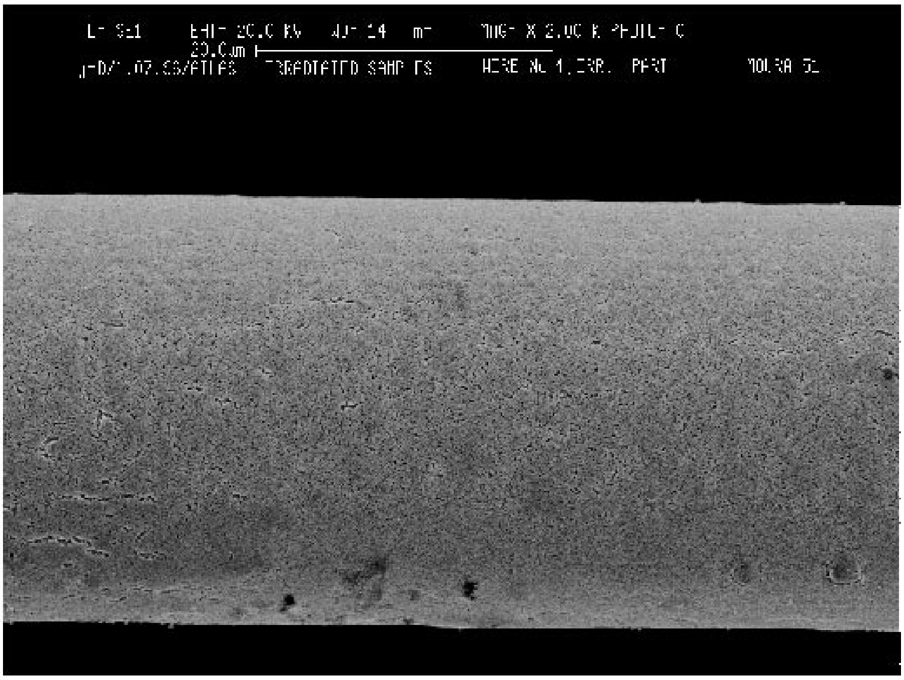
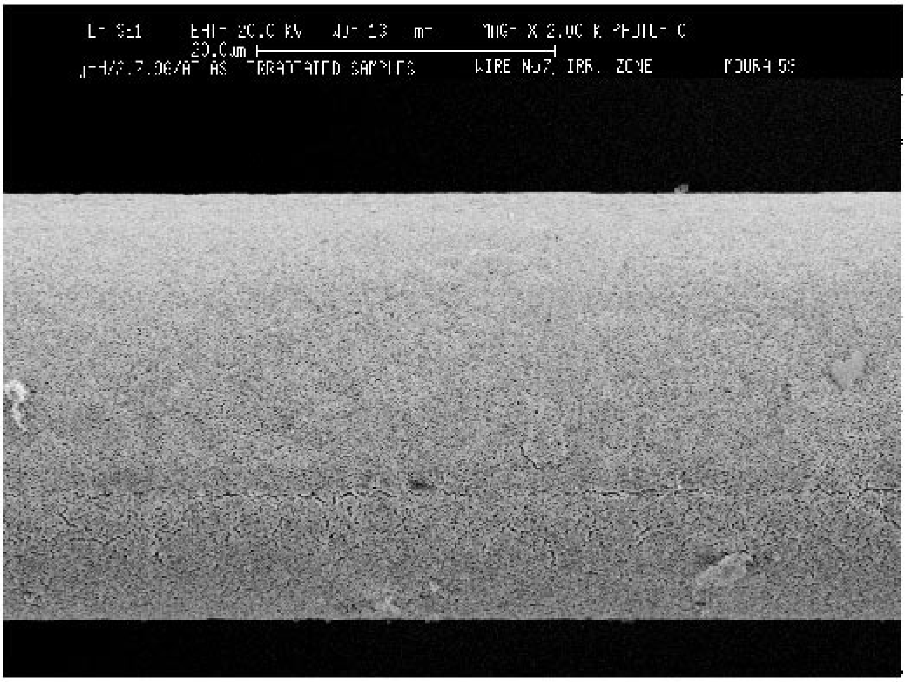


b



c

Fig.14(a-c) Photographs of anode wire of diameter 30 um in nonirradiated part before irradiated zone (a), in the center of irradiated zones(b,c) from the straws with cathode film without (b) and with (c) aluminium layer and low resistive carbon coatings in second run.