Ageing Phenomena in the LHCb Outer Tracker[1]

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Abstract

The LHCb Outer Tracker (OT) detector has shown to suffer from gain loss after irradiation in the laboratory at moderate intensities. Under irradiation an insulating layer is formed on the anode wire. The ageing is caused by contamination of the counting gas due to outgassing of the glue used in construction namely araldite AY103-1. The gain loss is concentrated upstream the gas flow, and at moderate irradiation intensity only. The ageing rate is reduced by longterm flushing and by the addition of a few percent of O_2 to the gas mixture. Furthermore, applying a large positive high voltage (beyond the amplification regime) removes the insulating deposits without damaging the wire surface. This paper presents both the characteristics of the ageing phenomenon and the beneficial treatments.

Key words: Tracking detectors, Gas detectors, Straw tubes, Ageing
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1. The LHCb Outer Tracker

The LHCb experiment aims at measuring CP violation and rare *B*-decays. For this, a tracking system is constructed close to the interaction point, and around a dipole magnet. The large area behind the magnet is covered by the Outer Tracker (OT) detector. The OT is a gaseous straw tube detector [1] and covers an area of approximately 5x6 m^2 with 12 double layers of straw tubes.

The straw tubes are 2.4 m long and 4.9 mm in diameter, and are filled with a gas mixture of Ar(70%)-CO_2(30%). The anode wire is made of 25μm gold plated tungsten wire, whereas the cathode consists of an inner foil of 40 μm electrically conducting carbon doped Kapton-XC and an outer foil of 25 μm Kapton-XC with 12.5 μm aluminium. The straws are glued to sandwich panels with 120 μm carbon-fibre skins and a 10 mm Rohacell core. Finally, the panels are joined by 400 μm thick carbon fibre sidewalls, resulting in a standalone detector module. A sketch of the module layout is shown in Fig. 1. The panels and the side walls are covered by a laminated foil of 25 μm Kapton and 12.5 μm aluminium to guarantee gas-tightness of the box and to provide a closed Faraday cage. Spacers at the ends of the module separate the two panels apart and pass the gas to the module. All glueing steps are performed using Araldite AY103-1 with the hardener HY991, cured at room temperature. To enhance the viscosity silica bubbles are added. The choice of epoxy was initially based on the literature [2], and subsequently extensively tested in prototype Outer Tracker modules [3]. Recently, it was discovered that, despite these extensive ageing tests in the R&D phase, the OT suffers from gain loss after moderate irradiation. This paper presents both the characteristics of the ageing phenomenon and the beneficial treatments.

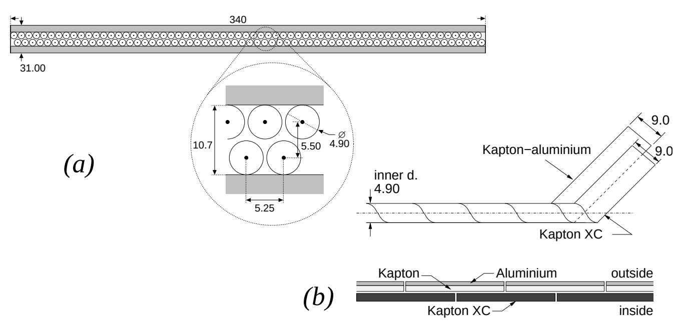

Figure 1: *(a) Module cross section. (b) The straws are winded using two foils, kapton-XC and a laminate of kapton and aluminium. All dimensions are given in mm.*

2. Ageing Phenomenon

2.1. Irradiation and monitoring setup

Irradiation tests were carried out on a small selection of final modules using a 2 mCi ^{90}Sr source. The high voltage on the anode wires was set at 1600 V and the gas flow (with a mixture of 70/30 Ar/CO_2) was 20 l/hr, corresponding to approximately one

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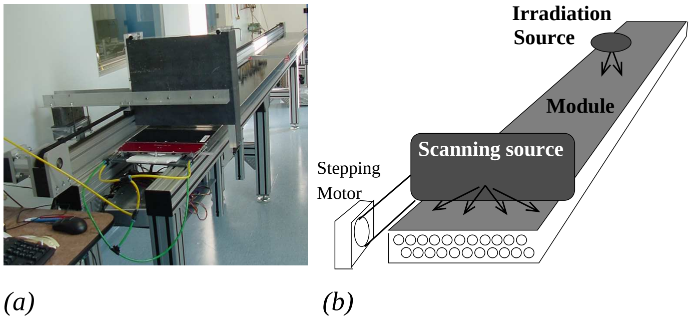

Figure 2: *(a) Photograph of the irradiation setup. The scanning source with which the performance before and after irradiation is measured is also shown. (b) Schematic view of the irradiation and scanning setup.*

volume exchange per hour. The source was collimated by a hole with a diameter of 6 mm at a distance of 5 mm from the module, resulting in an irradiated area of approximately 6×6 cm^2, see Fig. 3a.

Before and after irradiation the response of each wire in the module is checked with a 20 mCi ^{90}Sr source. The full module width is irradiated in steps of 1 cm along the length and the corresponding wire current is measured and recorded. The setup is depicted in Fig. 2.

A typical example of the gain loss after an irradiation of 20 hours is shown in Fig. 3b. The gain loss is quantified by comparing the 2-dimensional current profile before and after irradiation, by means of dividing the two current profiles. The observed gain loss shows several distinguishing features:

- The gain loss is not proportional to the source intensity: directly under the source the gain loss is less severe compared to the periphery. The gain loss for each measurement (corresponding to a pixel of 0.5×1 cm^2) is shown as a function of the irradiation intensity in Fig. 3c. This dependency is unchanged when the module is irradiated at different values of the high voltage, or with different source strengths.
- The gain loss occurs mainly upstream the source position, and is worse for larger gas flow. Presumably due to the creation of ozone in the avalanche region, the gain loss is prevented downstream, see Section 3.2.
- The gain loss is large, upto 25% for an integrated dose of 0.1 mC/cm at an intensity of 2 nA/cm.

2.2. Wire inspection

Samples of the anode wire were removed from an irradiated module for inspection with a sampling electron microscope (SEM). An irradiated wire with observed gain loss as described in the previous section, was compared with an unirradiated wire. An electrically insulating coating was found on the irradiated wire, see Fig. 4. The deposits were analyzed by means of energy-dispersive X-ray spectroscopy (EDX) which revealed the presence of carbon and indirectly that of hydrogen.

2.3. The Culprit

To identify the origin of the insulating deposits an aluminum test module was constructed with a minimum of components, containing the straw tubes, wires, wire locators and feed-through PCB's only. The module was sealed with a large O-ring. No signs of gain loss were observed after 480 hours of irradiation with maximum intensity of 75 nA/cm, corresponding to an integrated dose of approximately 0.13 C/cm.

Subsequently, the glue used in the construction of the OT modules (the epoxy Araldite AY103-1 with hardener HY991[1]) was added inside the gas volume. Significant gain loss was observed in 20 hours. In parallel, a second test module was constructed, identical to the OT modules in situ, but using a different glue (Tra-Bond 2115). No gain loss was observed after 1570 hours of irradiation with maximum intensity of 75 nA/cm, corresponding to an integrated dose of approximately 0.4 C/cm.

[1]Note that the manufacturer produced the last batch of AY103 in 2003, before switching to AY103-1, which does not contain dibutyl phthalate (DBP). A comprehensive review of materials in gas detectors can be found elsewhere [2].

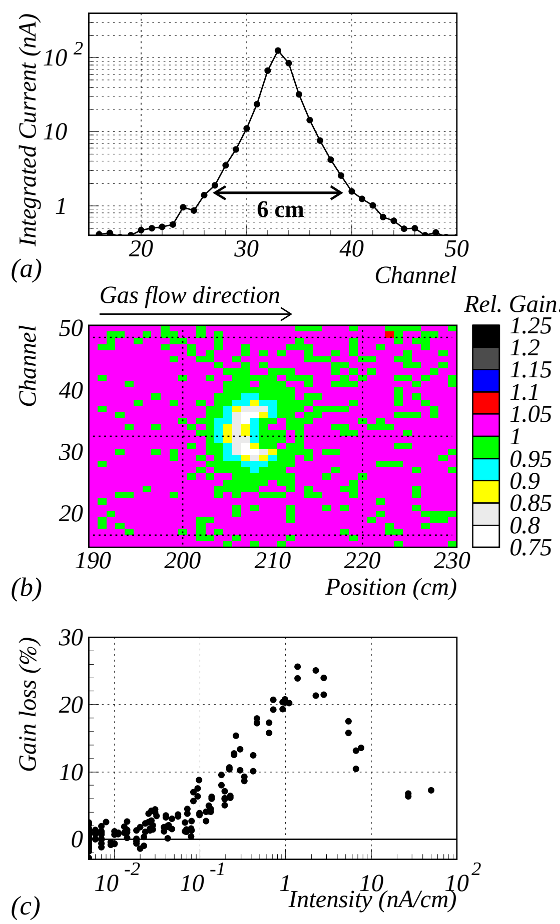

Figure 3: *(a) The integrated current per wire during irradiation. (b) The ratio of two* ^{90}Sr *scans before and after irradiation shows the relative gain loss after an irradiation of 20 hours. The source was centered on channel 32 on position 208cm. (c) The gain loss is shown for each measurement (pixel of 0.5×1 cm^2) as a function of the source intensity in that pixel. The gain loss is highest at moderate intensity, around 2 nA/cm.*

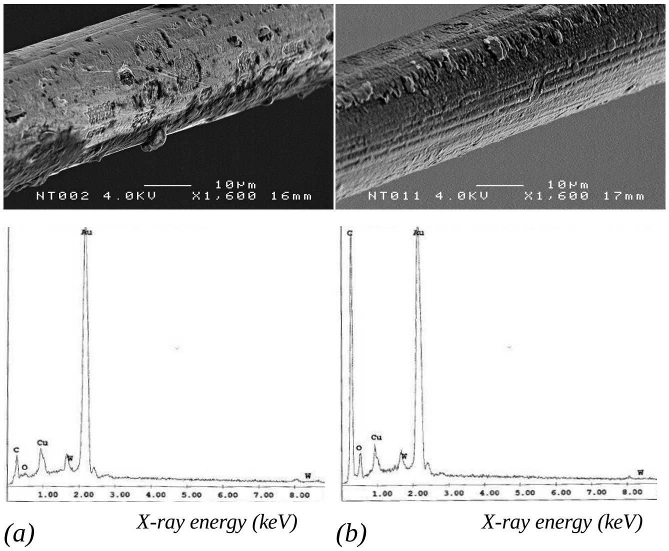

Figure 4: *(a) A SEM picture and EDX spectrum is shown for a sample of unirradiated outer tracker anode wire. (b) The same for an irradiated wire sample. A layer with a wax-like structure is observed, and a large amount of carbon is seen in the EDX-spectrum, indicating the presence of carbon-hydrates.*

We conclude that outgassing of Araldite AY103-1 is the origin of the carbon deposits on the anode wire, resulting in gain loss in the detector.

3. Beneficial treatments

The *shape* of the dependency of the gain loss on the irradiation intensity remains unchanged when parameters of the irradiation tests are changed, such as: high voltage, source type, source intensity, gas flow, gas mixture, humidity, irradiation time, or flush time. However, the maximum gain loss *does* vary, depending on some of these parameters. Beneficial effects on the maximum gain loss are described in this section.

3.1. Flushing

Given the fact that the araldite AY103-1 glue used in construction is a necessary ingredient to cause the gain loss in the OT detector, long term flushing is expected to transport away the vapours originating from outgassing of the glue. Indeed, Fig. 5 shows the maximum gain loss caused by an irradiation of 20hrs as a function of flush time. The ageing rate decreases significantly. All OT modules have been flushed continuously since the completion of installation in the LHCb experiment in Spring 2007.

In addition, experiments in the laboratory have shown that heating the modules at 40^{o}C might accelerate the outgassing of the glue, although the effect on the ageing rate differs from module to module. All modules in the experiment were heated for two weeks at 35^{o}C while flushed at 0.5 volume exchanges per hour.

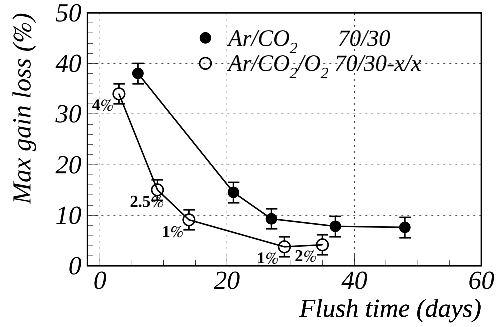

Figure 5: *The maximum gain loss decreases as a function of flushing time. Also, the ageing rate is smaller when a few percent of oxygen is added to the gas mixture, varying between 1% and 4%. The improvement does not strongly depend on the exact amount of oxygen.*

3.2. Additives

Oxygen has been used in other HEP experiments in the context of irradiation damage and gas detectors [4, 5]. Tests with the OT show that the ageing rate for gas mixtures with O_2 is reduced by approximately a factor two. The improvement in ageing rate with flushing time is similar for the nominal gas mixture Ar/CO_2 70/30, as compared to the gas mixture with a few percent O_2 added, see Fig. 5. The amount of oxygen has been varied between 1% and 4%, but the improvement does not strongly depend on the exact amount of oxygen.

Due to the small diameter of the OT straw tubes, the average signal height at the anode wire is only reduced by 11% (29%) when 2.5% (4.5%) O_2 is added to the gas mixture. Studies performed with the Garfield and Magboltz programs indicate that the drift speed is not affected.

A sensitive ozone (O_3) meter has been placed at the gas outlet during irradiation tests of OT modules. The ozone concentration increases with increased high voltage (Fig. 6a), indicating that ozone is formed in the avalanche region. The production of ozone under the source is presumably the reason that no gain loss is observed downstream of the source. This is consistent with the observation that the ageing rate is larger for increasing gas flow, when the produced ozone is transported away more efficiently.

The concentration of O_3 has also been determined for various oxygen concentrations, see Fig. 6b. For increasing oxygen concentration, larger amount of ozone has been measured, which might explain the beneficial effect of oxygen on the ageing rate. Above 1% of oxygen, the ozone concentration does not increase, supporting the observation that no difference in the ageing rate is observed between 1% and 4% O_2.

3.3. HV training

Once the detector suffers from gain loss caused by the irradiation, the insulating deposits can be removed by applying an high voltage at elevated values. Applying a reverse bias around -1450 V leads to fluctuating large dark currents above 1 μA.

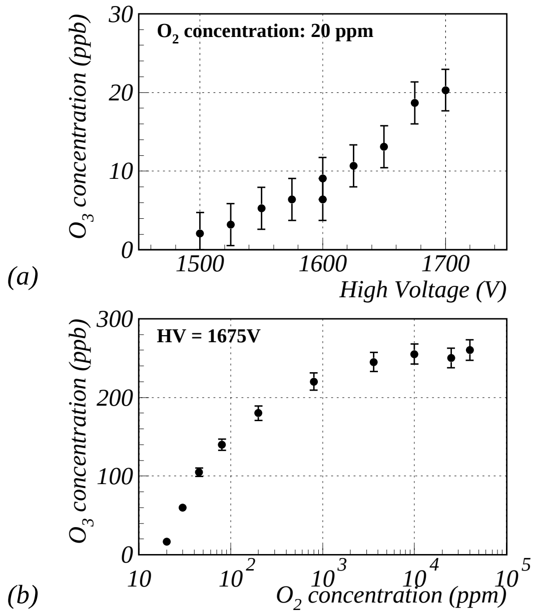

Figure 6: *(a) The ozone concentration increases for larger values of the high voltage, i.e. for larger amplification, indicating that ozone is produced in the avalanche. (b) The ozone concentration as a function of oxygen concentration. Above 1% O_2 the ozone concentration is constant.*

After a period of 24 hrs the gain is recovered. Similarly, a positive bias between 1850 V and 1920 V leads to dark currents of about 10 μA per wire. The gain is recovered in most cases after 20 hours. The microscopic mechanism is unclear (plasma sputtering of the wire surface? Elevated temperatures at the location of the discharges?).

The procedure with positive voltage has the advantage that the currents are more stable, being less sensitive to trips in the power supply. Secondly, since the OT detector is operated with positive bias, power supplies for positive voltages are readily available for the whole detector.

Potential damage to the anode wire has been investigated in the scanning electron microscope after a treatment of 35 hrs at 1880 V, subject to a current of 50μA. No signs of mechanical damage to the gold layer were observed. In addition, the relative peak heights of gold (Au) and tungsten (W) in the EDX spectrum indicated that the gold layer was undamaged.

4. Conclusion

The LHCb Outer Tracker detector has been shown to suffer from gain loss after irradiation in the laboratory at moderate intensities, peaking at about 2 nA/cm. Proper performance (and even recovering capabilities) at higher intensities hampered the observation of gain loss at accelerated ageing tests. During irradiation an insulating layer containing carbon is formed on the anode wire. The ageing is caused by contamination of the counting gas due to outgassing of the glue used in construction, namely araldite AY103-1. The gain loss is concentrated upstream the gas flow, due to the beneficial effect of ozone produced under the source and transported downstream. The ageing rate is reduced by longterm flushing and by the addition of a few percent of O_2 to the gas mixture. Although the Outer Tracker is expected to exhibit a noticeable gain loss after one nominal LHC year in a fraction of the OT modules, the effect on the hit efficiency and tracking performance will be small. Furthermore, applying a large positive high voltage (beyond the amplification regime) removes the insulating deposits without damaging the wire surface.

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