A simple and effective purifier for liquid xenon

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We describe a procedure to obtain ultra high electron lifetime in liquid xenon by means of a commercial Oxisorb cartridge and the distillation of the liquid. An improved ICARUS-type purity monitor chamber is described as well as details of the purification process. No charge attenuation is observed over the drifting distance (6 cm) at electric fields ranging from 800 down to 5 V/cm. This implies a free electron lifetime of at least several milliseconds. Results on the drift velocity dependence on the temperature are also reported.

1. Introduction

Liquid xenon (LXe) is characterised by many interesting features for calorimetry and imaging detectors, such as high density, very small Fano factor, high charge and scintillation yields, fast decay time of scintillation light, proportional scintillation, electron avalanche [1]. Proposals of LXe time projection chambers for cosmic gamma rays or double beta decay experiments [2,3] and homogeneous LXe calorimeters for future collider experiments [4,5], have motivated intensive R & D investigations devoted to improve the LXe purity. In fact, the purification of xenon requires a more careful handling with respect to the argon because of the higher temperature of liquid phase. Remarkable results in LXe were obtained by several groups [6-8] who obtained electron lifetimes higher than 200 μs. They all used similar purification methods namely, a chain of Oxisorb, molecular sieves and/or hot getters, where Xe is purified in gas phase at room temperature or higher.

Recently, in the frame of the ICARUS R & D activity, we tried to purify xenon gas using an Oxisorb cartridge including also molecular sieves. The resulting lifetime, for electron drifting in LXe in electric fields of a few hundred V/cm, was small, 4 μs to be compared with 3 ms lifetime we routinely obtain in LAr [9] using the same purifier. The present report describes a simple purification method which dramatically increases the electron lifetime in LXe to a value of several ms and presents an improved version of the ICARUS purity monitor chamber [9] designed to be sensitive to very high purity level.

2. The purity monitor chamber

The monitor chamber used for the present study is an improved version of the one described in a previous publication [9]. Fig. 1 shows the chamber configuration and the related electronics. In the new chamber the anode plate is replaced by a stainless steel plate with a gold-coated photo cathode on the centre surrounded by a cylindrical piece whose top is a gridded window (10 mm in diameter). The inner surface of the plate and the cylinder are fully coated with Cr2O3 by electrochemical deposition to absorb any reflected light. A 100 V potential is applied between cylinder and win-
dow (10 mm separation), producing an electric field inside the box. Electron clouds, photo produced by a 266 nm wavelength, 20 ns long laser pulse impinging on the photo cathode, drift towards the window. Only the electrons within the window aperture can enter the double gridded drift chamber. The latter has the same configuration as the previous chamber [9]; the drift distance between the grids is 50 mm.

As shown in the scheme (fig. 1) of the electrical connections, the window, the photo cathode and the anode are read together by the same charge sensitive preamplifier, in order to avoid the necessity of an absolute calibration. When the electrons drift between the cathode and the window, the amplifier receives two equal and opposite currents, from the cathode and the window, that cancel. To be precise the cancellation is not complete but is usually better than 99%.

The advantages of such configuration are the following.

![Image](image_url)

**Fig. 2.** Example of signal from the improved purity monitor chamber in gas argon. In figure the big spike before the signal is due to interference from the laser pulse.

a) All the reflected UV light is absorbed by the inner surface of the box, so that only electrons produced at the gold coated photo cathode can pass through the window.

b) Due to the drift time of the electron inside the box (see fig. 2), the signal from the window is delayed of about 10 μs with respect to the large noise from the laser pulse. The effort devoted to electrical shielding is then reduced and a more precise measurement of the cathode signal can be easily achieved.

Fig. 2 shows an example of signal from the monitor chamber in gas argon. The height of the first (positive) step is proportional to charge $Q_1$, leaving the cathode grid, the height of the second (negative) one is proportional to charge $Q_2$, reaching the anode. In the case shown the anode signal is lower than the cathode one because of the very large lateral diffusion of the electrons in gas phase [1]. Hence part of the electron cloud is lost on the race track of the monitor chamber.

As discussed in ref. [9] the maximum measurable lifetime, that is obviously larger at smaller fields, is in the range of several milliseconds.

3. The purification process

The scheme of the xenon purifier together with its filling system is shown in fig. 3. A 4 l storage (S1) is the primary container for xenon gas of unknown purity, while a 30 l container (S2) is only used for temporary storage. The whole system is built using high vacuum components and we employ high vacuum cleaning procedures. The Oxisorb (Messer Griesheim GmbH Large aluminium cartridge) after having been evacuated during more than one month was filled with xenon gas at about 3 bar. The transfer lines have been evacuated and baked out for more than 100 h at 200°C and the chamber at 120°C (limited by indium seals). The final vacuum pressure achieved on the system was smaller.
than $10^{-7}$ mbar and the degassing rate in the chamber (350 cm$^3$) was about $4 \times 10^{-10}$ mbar l/s.

The following steps were performed to purify and liquefy the Xe into the monitor chamber.

1) The xenon gas was transferred through the Oxisorb from S1 to S2 which was cooled by a liquid nitrogen bath. It took about 3 min to transfer all the gas (about 300 l atm). This operation was performed to flush away from the filter all the impurities that cannot be efficiently trapped by the filter itself (e.g. CO$_2$).

2) The liquid nitrogen bath was removed from S2 and the xenon gas was restored into S1 cooled using liquid nitrogen without passing through the Oxisorb, until a residual pressure of 200 mbar was left in S2. At that time the transfer was stopped and the residual gas in S2 evacuated. During the whole operation the temperature of S2 was steadily increasing from LN$_2$ temperature but it was monitored to be always below 170 K. Finally S1 was left to warm up naturally while the transfer lines were then evacuated and baked again for several days.

3) S1 was cooled down from room temperature to a temperature between 187 K and 182 K by a liquid mixture of nitrogen and Freon 11. This condition was kept for 5 h up to complete thermalization of the liquid.

4) Finally, the xenon gas was evaporated, passed through the Oxisorb and condensed into the monitor chamber maintained at 173 K by a liquid Freon 11 bath. The temperature was controlled by a cooling device (HAAKE PK101). The filling of the chamber was completed in 2 h.

During these operations two main purification processes took place: first, the Xe distillation was performed (steps 2 and 3) at low temperature so that most of the impurities (CO$_2$, H$_2$O, etc.) remain frozen on the walls of S1 and S2; second, the usual chemical and physical purification (step 4) through the Oxisorb (mainly O$_2$).

4. Results and discussion

Figs. 4a and 4b show typical signals from the monitor chamber at 10 and 800 V/cm, respectively. In both figures, no significant difference between the heights of the steps is observed. The ratio $Q_e/Q_0$ is close to unity (> 0.99) for electric field intensities ranging from 5 to 800 V/cm. This means that the electron lifetime is in any case longer than our measurement limits. As discussed in ref. [9] we calculate that these are in the range of several milliseconds. The liquid was kept in the chamber for 3 weeks and no noticeable degradation in the measured electron lifetime was observed for this period.

Notice that steps 1 and 2 of the purification process described in section 3 are only necessary when using a new Oxisorb cartridge. In fact we obtained the same high electron lifetime values with a different sample of xenon gas, with a previously flushed Oxisorb cartridge and proceeding through steps 3 and 4.
We already noticed during the ICARUS test the importance of flushing the Oxisorb cartridge while purifying LAr. This process was the decisive step to improve the electron lifetime in LAr from 100–200 μs to more than 2 ms. A possible explanation of this effect could be the presence of carbon dioxide inside the Oxisorb cartridge with a concentration higher than the one in the initial argon. In a previous publication [9] we showed that CO₂ in LAr acts as an electronegative impurity with a considerably high attachment rate constant (1.6 × 10⁻²⁹ m⁻³ s⁻¹ at 800 V/cm). Nevertheless, due to the very low temperature of LAr the CO₂ molecules are easily and steadily adsorbed on the inox walls of the LAr container; this greatly reduces the CO₂ concentration in the liquid. In the case of LXe a similar adsorption effect is not expected because of the higher temperature. Hence particular care has to be devoted in eliminating CO₂ during the purification process of Xe.

5. Other measurements

Using the ultra pure LXe in the monitor chamber we measured the lifetime and the drift velocity \( v_d \) at different temperatures between 167 K and 200 K.

No dependence of the lifetime on the temperature was observed within the sensitivity of our monitor.

The drift time over the 50 mm gap between the first and the second grid gives a careful measure of \( v_d \). Fig. 5 shows the temperature dependence of \( v_d \) at a fixed field of 600 V/cm. In this test the xenon temperature was deduced both by its vapour pressure and by the bath temperature monitored with a thermometer fixed on the outer surface of the chamber. The accuracy on the temperature measurement is better than 1°C while the total error on \( v_d \) (statistical plus systematic) is smaller than 1.5%. Increasing the temperature, the drift velocity decreases almost linearly with a slope of \( 1.2 \times 10^{-3} \text{ cm s}^{-1} \text{K}^{-1} \). This result indicates that the temperature stabilization in a LXe drift chamber is very important in order to get good time resolution.

6. Conclusions

Electron lifetime of several milliseconds was achieved in liquid xenon after purification using an Oxisorb filter and a simple distillation procedure. The result, together with a long attenuation length of scintillation light (≈ 1 m) [11], makes the LXe a very promising medium for applications such as fast scintillator calorimeters, TPC’s self-triggered by the scintillation signal and WIMPs detector such as the one proposed by our collaboration [11]. In order to achieve good time resolution in a drift chamber a very precise temperature control of LXe is required because drift velocity changes with temperature as much as \( 10^{-3} \text{ cm s}^{-1} \text{K}^{-1} \) in a field of 1 kV/cm.

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References