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SIMPLE METHOD FOT MEASUREMENTS OF DRIFT VELOCITY AND LIFETIME OF ELECTRONS IN CASEOUS AND LIQUID KRYPTON

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Simple method for measurements of drift velocity and lifetime of electrons in gaseous and liquid krypton

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Abstract

New method for measurements of the drift velocity V_d and electron lifetime τ in gaseous and liquid krypton is suggested. The principle of the monitoring system is based on the usage of fast gas discharge radiating soft X ray. These X rays produce photo electrons on the cathode of ionizing chamber. The drift velocity and electron lifetime are obtained from analysis of pulse shape.

1. Introduction

Gaseous and condensed noble gases are extensively used as a working media for ionization detectors of elementary particles, see for example [1–5]. The basic characteristics of these detectors like time, spatial and energy resolution are determined by drift velocity V_d of electrons and its lifetime τ in working media. It is known that even a little amounts of electronegative impurities dramatically affect on the parameters of detecting media [6]. For this reason the development and the implementation of a prompt and accurate method to measure V_d and τ in noble gases and liquids is an important problem.

Below well known methods are listed. Radioactive sources (α, β) and minimum ionization particles can be used for measurements of V_d and τ [7,8]. The weak point of this method is low signal to noise ratio therefore it is often impossible to make on-line measurements with needed accuracy.

A method based on the production of electrons into the ionizing chamber by means of short pulses of X-ray with energy about 30 keV coming to the chamber volume through a thin window was proposed [9]. This method can not be use in large detectors.

In experiments [10,11] short high power pulse of ultraviolet laser radiation was used to extract photo-electrons out of the metal plate of ionizing chamber filled by liquid argon (krypton). The advantages of this method are large signal to noise ratio, possibility to measure V_d and τ with a single laser pulse. High price of UV-laser and the necessity to input the laser light into the cryogenic volume are disadvantages of this method.

The purpose of present work was to develop low price and simple method for the fast measurement of detecting properties of gaseous and condensed noble gases. The method is based on fast pulse gas-discharge operating inside of monitoring device and radiating soft X-ray. Developed monitoring system is used in LKr calorimeter of the «Kedr» detector [1,2,4].

2. Experimental device

Figure 1 shows schematic view of the monitoring device. Two electrodes 3,4 of the ionizing chamber are placed inside of cryostat 1. The gap between electrodes can be varied by moving of electrode 4 along the ceramics roads 5. The discharge unit is installed at the centre of flange 2. The discharge gap between electrodes is equal to 0.1mm. Both electrodes are made of tungsten wire of 1mm in diameter. The cylindrical shield 6 was used to collimate the radiating photons and to reduce the electromagnetic noise from discharge to the signal electrode 4. Output hole of the shield was screened by tungsten grid with sells of 0.1×0.1mm and transparency about 80%. The photons come to the signal electrode through the hole in electrode 3 also screened by the grid. Two types of the signal electrode

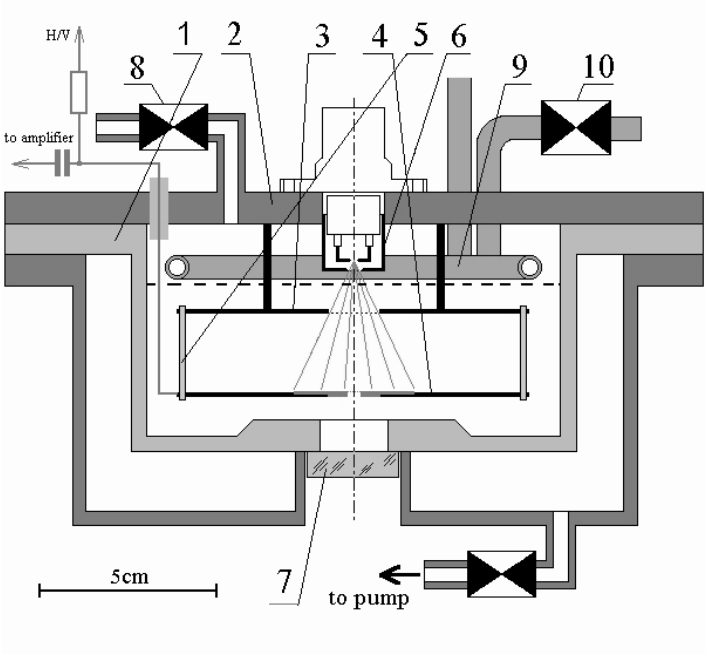

Fig. 1. Schematic view of the experimental device.
1 – cryostat; 2 – flange; 3,4 – grounded and signal electrodes of the ionizing chamber; 5 – ceramics roads; 6 – cylindrical shield of discharge unit; 7 – transparent window; 8 – pipe with valve for pumping of cryostat and for filling with Kr; 9 – copper pipe for krypton condensation; 10 – valve for adjusting of the liquid nitrogen flow.

were used in experiments: pure magnesium (work function $W_{Mg} \cong 3.5$ eV) or nickel ($W_{Ni} \cong 5$ eV). The hole of 1.5 mm in diameter was made in the center of electrode for the observation of the discharge light through the window 7 in the bottom of the chamber.

Experiments were carried out with gaseous and condensed krypton. The krypton liquefaction was performed by means of liquid nitrogen passing through copper pipe 9. Control of the pipe temperature was made by adjusting of liquid nitrogen flow using the valve 10 on the output end of the pipe.

During the experiments the liquid krypton temperature was 120°K. It was monitored by the pressure of the gaseous krypton above the liquid. To reduce the warm flow to the chamber filled with condensed krypton all exterior parts of device were cowered by synthetic foam and also the vacuum insulation gap was pumped below 10^{-1} Pa.

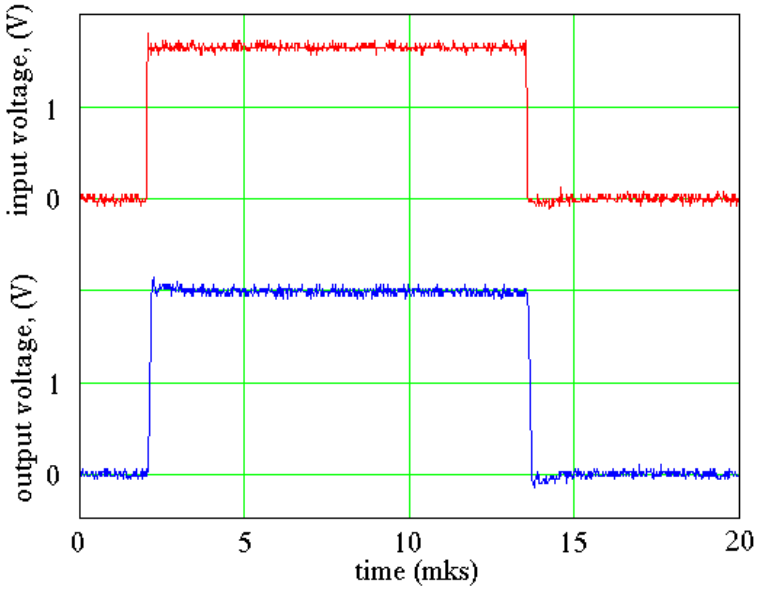

Fig. 2. Calibration signals of the current amplifier.

The discharges were initiated with frequency ~50 Hz , pulse duration of 1ns or 5 ns and amplitude about 6 kV. Signal from cathode of the ionizing chamber after the current amplifier was recorded by oscilloscope Tektronix TDS 360. The Fig.2. shows the results of calibration of the current amplifier. Output signal

corresponds to the input current of the amplifier equal to $4.12 \cdot 10^{-6}$ A. From these data one can find that the sensitivity of amplifier was $(2.06 \pm 0.01) \cdot 10^{-9}$ A/mV. It is seen also that the rise time of the amplifier is less than 0.2 μs.

3. Experimental results

As it was mentioned the proposed monitoring system was tested with gaseous and liquid krypton.

3.1 Results with gaseous krypton

After pumping of the ionizing chamber to pressure less than 10^{-1} Pa it was filled by industrially produced krypton to the pressure of 0.05 ÷ 0.25 MPa without any preliminary purification.

The typical output signal of the ionizing chamber is shown on the Fig.3. It was obtained at the electric field between the plates of chamber equal to 300 V/cm and pressure of krypton of 0.25 MPa. The positive polarity of signal corresponds

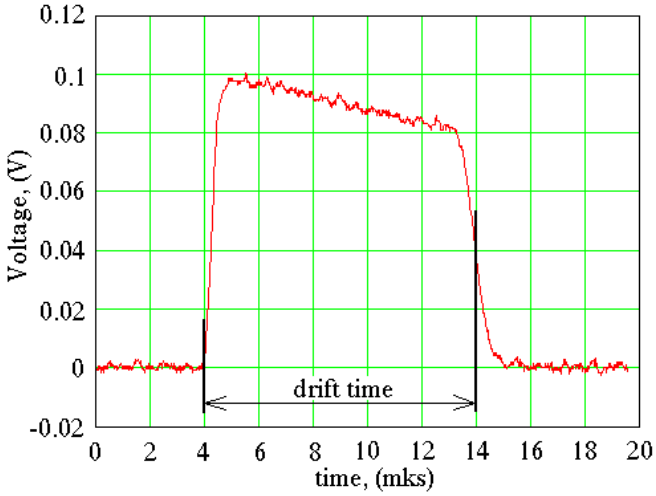

Fig. 3. Signal of ionizing chamber.
Pressure of krypton is equal to 0.25 Mpa; electric field E = 300 V/cm.

to the drift of electrons from the negatively charged signal electrode (photo-cathode) to the positive grounded electrode. Amplitude of the signal is proportional to the discharge pulse duration and only slightly (15%) changes by reducing of the krypton pressure from 0.25 MPa to 0.1 MPa. By this means electrons are produced for the most part out of the photo-cathode but not due to ionization of krypton atoms in volume between electrodes of ionizing chamber. After the leading edge of the signal duration of which is determined by the rise time of current amplifier the amplitude of signal linearly decreases during about 8 μs, then follows trailing edge with characteristic time more than 1μs. The decreasing of amplitude is caused by attachment of electrons by electronegative impurities during its drift in krypton. Since the reducing of pulse amplitude follows to the exponential low, it is easy to find electron lifetime.

The average drift time of electrons in electric field between the plates of ionizing chamber is shown on the oscillogram. It is the time between the beginning of pulse and the middle of trailing edge. For our opinion more longer trailing edge of the pulse is result of diffusion of the of electron cloud during its drift in krypton. The maximum number of photoelectrons extracted from the cathode by discharge photons ranges up to 10^8. One should note that it is not constant from pulse to pulse and can be changed in a few times.

The emission of electrons from the signal electrode should be suppressed if the high voltage polarity changes to be positive. In this case we expect to have the signal caused only by ionization of krypton in volume of the chamber. The signal changes polarity to negative and reduces amplitude approximately three times but its shape remain the same. The signals obtained at different polarity of the signal electrode are shown on the Fig.4 for comparison. Dotted line corresponds to the negative signal with inverted polarity and its amplitude is normalized to the signal with positive polarity. We did not have any signal from the signal electrode if the photons came to it through the hole in grounded electrode which was not covered by the grid. So the ionization of krypton in the chamber volume really did not take place and the signal with negative polarity was caused by the photoeffect on the input grid of the grounded electrode.

The measurements of electron lifetime τ and its drift velocity V_d in krypton as function of electric field strength have been performed. These data are presented on the Fig.5 and Fig.6. To determine electron lifetime decreasing part of signal was approximated by the exponential function. As a criterium of correspondence between exponent parameters and experimental data χ^2 criterium was used. One can see from the Fig.5 that electron lifetime slightly increases with electric field. On the Fig.6 besides of our data for drift velocity the results of measurements from [11,13] are presented. One should note that agreement of

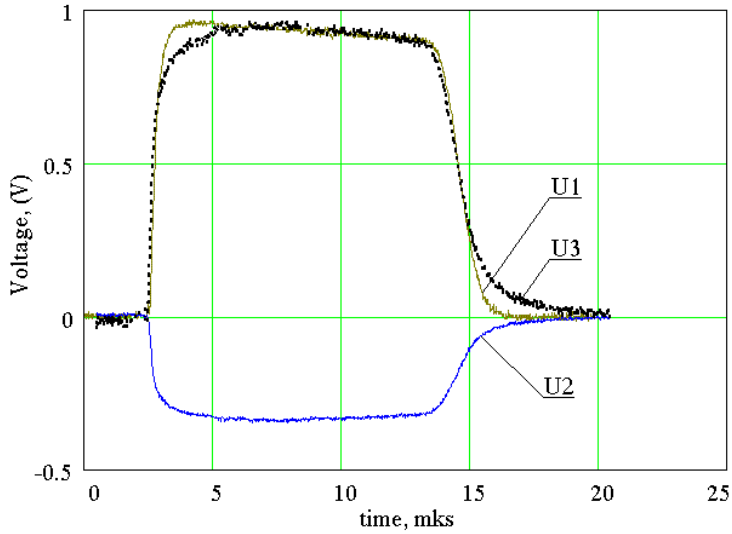

Fig. 4. Signals at different polarity of the electrodes of ionizing chamber.
U1 — E = –200V/cm; U2 — E = +200 V/cm; U3 =U2· (–2.8).

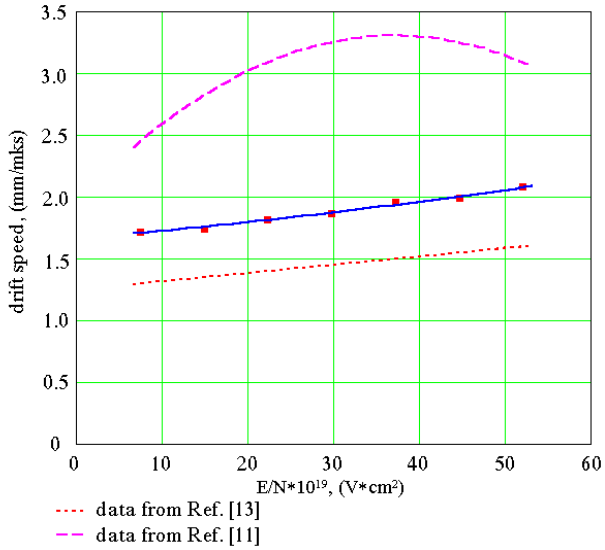

Fig. 5. Electron drift velocity in krypton at pressure 0.25 MPa
as function of E/N ratio.

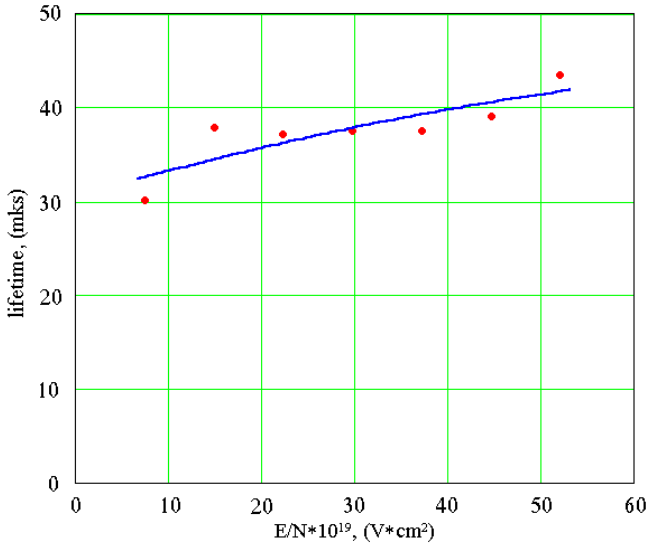

Fig. 6. Electron lifetime in krypton at pressure 0.25 MPa as function of E/N ratio.

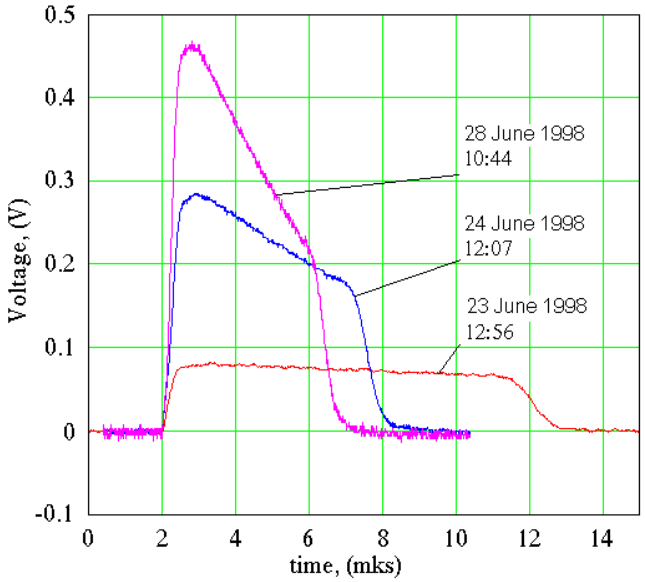

Fig. 7. Signals of ionizing chamber for different time after the gas filling.

the data has only qualitative character because properties of krypton depend on impurities. To confirm this conclusion on the Fig.7 the signals for the same gas portion and the same pressure and electric field are shown for different time after the gas filling. It was established that in one day the drift velocity changes by nearly two times and electron lifetime decreases approximately in five times. We suggest that the reason of these changes are impurities coming to the gas from the constructional materials. It is necessary to note that before final assembling all parts of monitoring system were cleaned and vacuum tempering was made.

To determine the effective energy of radiation emitting by discharge, photocathodes made of magnesium (work function $W_{Mg} \cong 3.5$ eV) and nickel ($W_{Ni} \cong 5$ eV) were used. Experiment shows that in both cases output signals of ionizing chamber look the same. Possible explanation could be that the discharge radiation has energy more than work functions of materials used. It was confirmed in additional experiments when output collimating hole of discharge unit was screened by 1mm quartz plate. In this case we did not have output signal. Consequently, on the one hand the effective energy of discharge radiation is more than energy edge of transparency of the quartz which is equal to 6 eV. On the other hand energy of radiation is less than ionization potential of krypton ($W_i = 13{,}99$ eV) since we do not observe volume ionization of krypton.

3.2 Results with condensed krypton

An example of oscillogramme for condensed krypton on the Fig.8 is presented. One can mention that in first experiments with distance between the electrodes of ionizing chamber equal to 20 mm the trailing edge of the pulse

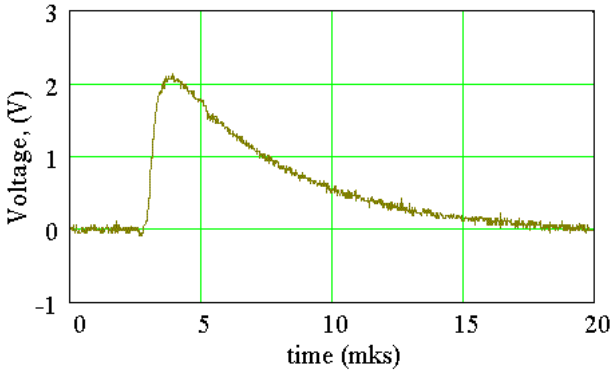

Fig. 8. Example of signal obtained with liquid krypton.

was clearly seen only in electric field more than 500 V/cm. For this reason it was difficult to determine the electron drift velocity at low electric field. To overcome this inconvenience the distance between electrodes was reduced from 20 mm to 14mm and gaseous krypton was passed through the cartridge with oxisorb before condensation of the gas. Signal of monitoring system for this case is shown on the Fig.9.

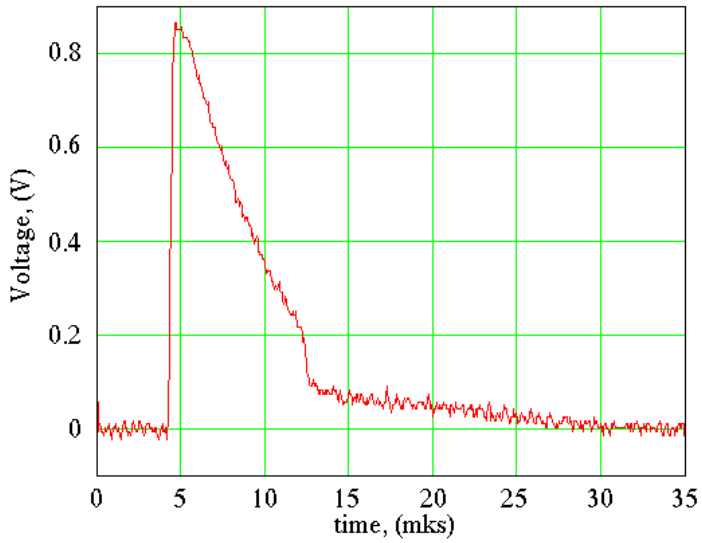

Fig. 9. Example of signal for purified krypton and reduced distance between electrodes of ionizing chamber.

Due to krypton purification the electron lifetime was increased and thus the drift time of electron between electrodes was clearly observed. In the case of condensed krypton the amplitudes of signals become distinctly higher in comparison with the gas. That can be related with known fact that electron work function from metal to liquid decreases by 0.4 ÷ 0.45 eV [6]. In addition one can see that after fast trailing edge of the signal there is long (about 15 – 20 μs) tail. According to publications [6,14,15], transition of electrons from liquid to metal can be delayed, if there is gas in gap between and the signal behaviour after trailing edge was determined by presence of gas bubbles on the surface of the top electrode.

One can mention that with positive high voltage polarity the same results like with gaseous krypton were obtained. No presence of volume ionization in liquid krypton by discharge radiation was observed.

On the Fig.10 the dependence of the electron drift velocity in condensed krypton as a function of electric field is presented. Our data are in reasonable agreement with results given in [11].

The electron lifetime in liquid krypton as function of electric field is shown on Fig.11. In comparison with results for industrial krypton the same gas after passing through the OXISORB cartridge before liquefaction had approximately two times increased electron lifetime.

Let us finally discuss the possibility to apply the monitoring system for measurements in condensed noble gas contained for example in the calorimeter. In this case it is not necessary to arrange system so that its electrode would be placed in a liquid and the discharge unit placed in a gas. The device may be immersed into the liquid as a whole. Only heating element in the discharge unit should be additionally installed. When heated by current heating element evaporate liquid and in result the discharge unit will be filled with the gas.

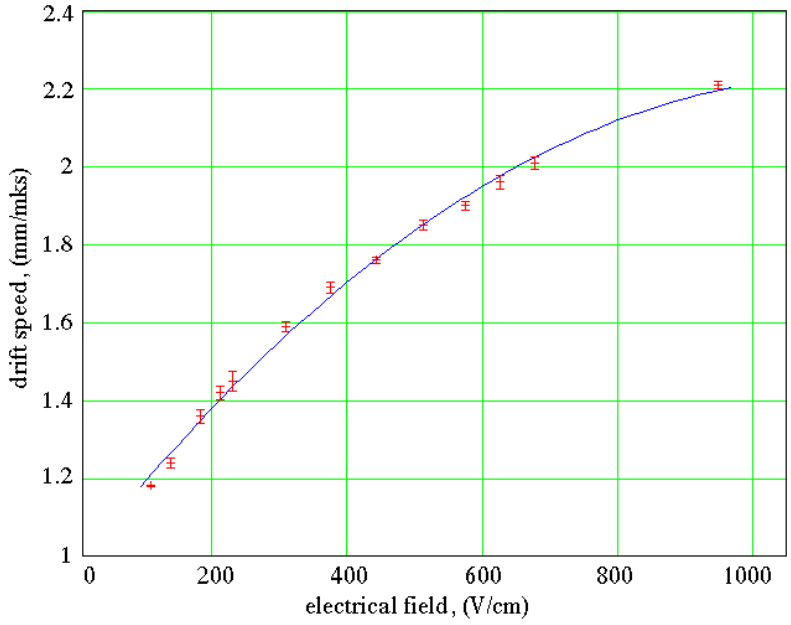

Fig. 10. The electron drift velocity in a LKr as a function of electric field.

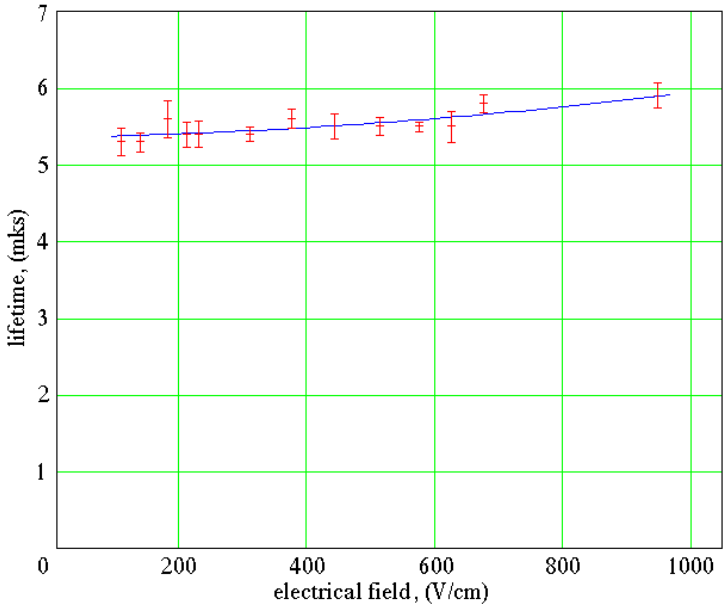

Fig. 11. The electron lifetime in a LKr as function of electric field.

In principle it is possible to use cryogenic discharge between electrodes directly in a liquid. Our experience show that in this case the erosion of electrodes take place more intensively than in the case of the discharge in a gas. In addition the amplitude of the pulse applied to the electrode could be increased at least by two times to obtain stable discharge in a liquid.

4. Conclusions

A monitoring device suited for measurements of drift velocity and electron lifetime was proposed and successfully tested. Usage of fast discharge source of photons allows one to obtain high enough signal in the ionizing chamber.

This enables the using of developed method for on-line monitoring liquid as well as gaseous krypton.

Acknowledgments

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