Effect of the electric field on the primary scintillation from CF_4

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Abstract

The effect of an electric field on the primary scintillation from CF_4 in the ultraviolet and visible wavelength regions (200 - 800 nm) is reported. The study was performed in the pressure range from 1 to 5 bar and at electric fields of up to 2 kV/cm. Photon emission spectra, fully corrected for the detection response, and the absolute photon yields in the ultraviolet and visible regions are reported. The CF_4 emission spectra and the photon fluxes show no variations with the field at low pressures (~1 bar), while at higher pressures the effect of the field on the scintillation is strong: the ultraviolet emission intensity increases and the visible intensity decreases with the field strength. Time spectra of the primary scintillation for several applied electric field strengths are also reported for the two wavelength regions of light emission.

Key words:
CF_4, primary scintillation, emission spectra, photon yield, time spectra

1. Introduction

CF_4 (carbon tetrafluoride) possesses a unique combination of physical properties which makes it a very attractive detection medium, both for charge- and optical read-out. CF_4 is a heavy molecule containing only low Z atoms. The gas has high stopping power, the drift velocity is high and the diffusion is low [1]. The scintillation properties of CF_4 are also appealing: the photon emission is distributed over a broad spectral range (from vacuum ultraviolet to visible), the gas is transparent for its own emission and the photon yields are quite high (see e.g. [2]).

This article is a follow-up paper for our previous publication [3], where we have reported results on the pressure dependence of the primary scintillation from CF_4 (emission spectra and photon yields) in the absence of an electric field. However, for detectors operating with a drift field it is essential to study the effect of the field on the primary scintillation. Here we present results for the pressure range from 1 to 5 bar showing that the application of an electric field with only a few hundred V/cm already strongly influences the primary scintillation at high pressures. We also give time spectra of the primary scintillation for pressures from 1 to 3 bar at several electric field strengths, and we discuss possible physical mechanisms which can explain the observed results.

2. Experimental techniques

Fig. 1(a) shows a schematic drawing of the setup used to record emission spectra and to measure absolute photon fluxes. CF_4 was fed into a gas cell, which was evacuated to ~10^{-6} mbar prior to every gas filling. The output window (fused silica,

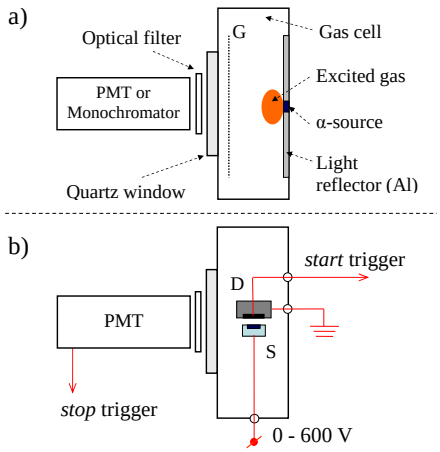

Figure 1: Schematic drawing of the setups used for spectral studies and photon yield measurements (**a**) and for time-resolved measurements (**b**). G is the grid, D is the solid state detector and S is the α-source.

Ø 40 mm) of the cell was directly facing an Am-241 α-source. The source was mounted 0.2 mm behind the surface of a flat light reflector, installed parallel to the window. The reflector, made of aluminum, had a reflectivity of 0.80 ± 0.08 in the wavelength range of the study. The gas was irradiated by α-particles through a 0.8 × 6 mm^2 aperture in the reflector. The rate of the α-particles entering the gas was 42100 ± 100 s^{-1} and the average energy deposited by an α-particle in the gas was 3.70 ± 0.05 MeV. A metal grid (optical transmission of 0.89) was installed parallel to the reflector at a distance of 26 mm. The reflector was kept at ground potential while voltages of up to 5 kV were applied to the grid. The CF_4 with 99.998% gas purity was supplied by Air Liquide.

A monochromator (Applied Photophysics 7300) and a photo-

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multiplier tube (PMT) C31034 from RCA were used to record the emission spectra. The spectral response of the detection system was established using recently calibrated (NIST[1]-traceable) light sources: a deuterium lamp (200 - 400 nm) and a tungsten halogen lamp (380 - 800 nm).

The measurements of the absolute number of photons emitted by the gas (in the following referred to as "flux measurements") were performed directly with two PMTs, Photonis XP2020Q (UV region) or Hamamatsu R1387 (visible region), using broadband optical filters to limit the wavelength range and applying the point-light-source approximation: it was shown that the measured count rates decrease as the inverse square of the distance between the light source and the PMT. A detailed description of the measurement technique and all the calibration procedures have already been given in our previous paper [3].

Fig. 1(b) shows a drawing of the setup used to record time spectra. In this case, another α-source (Am-1U, Ortec; activity ~600 α-particles per second) was installed at a distance of ~2 mm from a solid state detector (PIPS, Canberra). Alpha-particles, after depositing part of their energy in the gas, were registered by the solid state detector, giving the "start" signals. The primary scintillation photons, recorded by a PMT (XP2020Q in the UV or R1387 in the visible region) provided the "stop" signals. Optical filters were again used to limit the wavelength range of the detected photons: a Schott UG11 filter was applied in the UV region, and a UV-block filter (450 nm cut-off) was used in the visible region. After amplification, shaping and discrimination, the PMT-signals were sent to a time-to-amplitude converter and the time-resolved information was recorded using a multi-channel analyzer. The electric field was established between the grounded detector and the all-metal α-source by applying voltages of up to 600 V. The correct operation of the complete time-resolved detection system was confirmed by recording time spectra from molecular nitrogen in the so-called second positive emission system (see e.g. [4]) and comparing the obtained decay rates with well-established data from literature.

3. Results and discussion

3.1. Emission spectra and photon yields

Emission spectra were recorded in the wavelength range from 200 to 800 nm at pressures from 1 to 5 bar. All spectra were corrected for the spectral response of the detection system. Gas aging during a rather long recording time of a spectrum (~3 h) appeared as a uniform reduction of the intensity of the visible emission. This effect was accounted for by recording count rates at several wavelengths with fresh gas fillings and applying the required corrections to the spectra.

Fig. 2 shows the emission spectra recorded at 1, 3 and 5 bar with and without an applied field of 2 kV/cm, which is the maximum field strength that can be safely used in this setup. At 1 bar the application of the field had no effect on the spectral

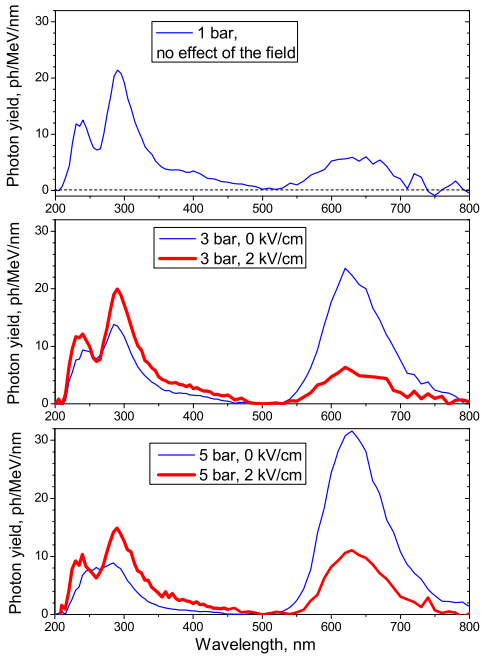

Figure 2: Wavelength-resolved primary scintillation from CF_4 for 1, 3 and 5 bar recorded with and without the applied electric field. The photon flux data are given in "photon yield per nm" units.

profile and on the intensity of the emission. However, at higher pressures the effect is very significant: the application of the field strongly reduces the intensity of the visible emission and leads to an increase in the UV emission. Moreover, at 5 bar the electric field causes a spectral redistribution of the UV emission: when the field is applied, the spectral profile of the UV emission changes and it becomes essentially the same as the profile observed at lower pressures.

When the emission spectra are recorded, the monochromator collects light only from a limited fraction of the light emitting volume. Since the characteristic diameter of this volume significantly increases with the inverse gas pressure, the raw spectra recorded with the monochromator at different pressures are differently affected by the light collection efficiency. In Fig. 2 we compensate for this difference applying scaling factors to the individual spectra. These factors were obtained from absolute photon flux measurements performed directly with the PMTs (see Section 2). Using the data on the absolute number of emitted photons, and applying the information on the average energy deposited by α-particles in the gas per second, we calculate the photon yield for the CF_4 primary scintillation (see vertical axis units of Fig. 2). The photon yield is defined here as the number of photons emitted per 1 MeV of energy deposited in the gas. The systematic uncertainties are about 15% in the UV and about 20% in the visible wavelength region.

The wavelength-integrated photon flux as a function of the CF_4 pressure was measured directly with the PMTs at several field strengths, and it is shown in Fig. 3 for the UV emission component (220 - 500 nm) and in Fig. 4 for the visible component (500 - 800 nm). The relative uncertainties are below 10% for the UV component and below 15% for the visible one. Note

[1]National Institute of Standards and Technology, U.S. Dept. of Commerce

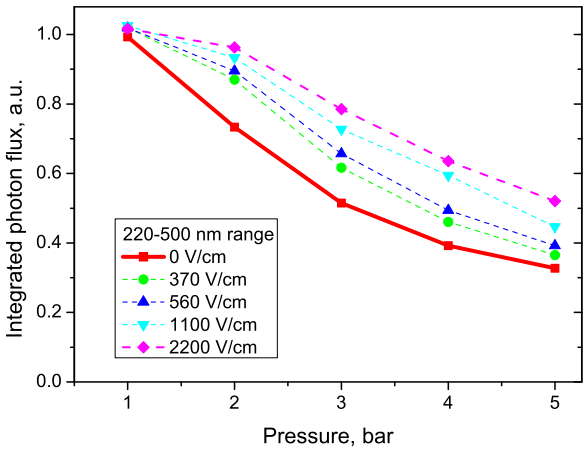

Figure 3: Primary scintillation from CF_4: UV photon flux (220 - 500 nm) as a function of the gas pressure and the strength of the applied electric field.

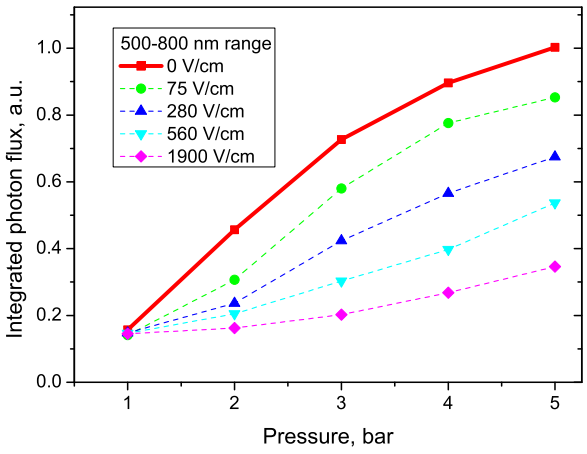

Figure 4: Primary scintillation from CF_4: photon flux in the visible range (500 - 800 nm) as a function of the gas pressure and the strength of the applied electric field.

that both spectral and flux measurements give the same results for the field dependences providing a good cross-test.

3.2. *Time spectra*

Time-spectra of the primary scintillation (i.e. the distributions of the photon emission probability vs. time) were recorded in the pressure range from 1 to 3 bar. Data for higher pressures could not be obtained in this setup due to the very short ranges of the α-particles. The UV emission was analyzed using the XP2020Q PMT with the UG11 optical filter. Therefore, the obtained data have an effective wavelength range of 260 - 370 nm. The time spectra of the visible emission were recorded using the R1387 PMT with the UV-block filter, providing an effective range of 450 - 800 nm.

The time spectra of the UV emission are nearly identical for the gas pressures from 1 to 3 bar. An example for 3 bar is shown in Fig. 5. The decay is nearly mono-exponential (typical effective lifetimes are ~5 ns) with a very weak non-exponential "tail", which is visible at time delays above 40 ns. The application of the electric field practically does not change both the

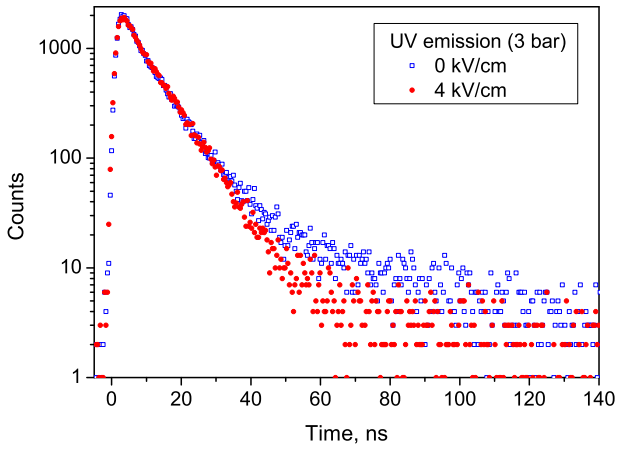

Figure 5: Primary scintillation from CF_4: time spectra of the UV emission in the range of 260 - 370 nm with and without the applied electric field.

shape of the time spectra and the effective decay rate.

Unlike the time spectra recorded in the UV range, time spectra of the visible emission show a significant pressure dependence and demonstrate a strong non-exponential characteristics at later stages of the decay (see Fig. 6). Typical effective lifetimes are between 10 and 15 ns. The peak in the time spectra shifts to later times with increasing gas pressure. The effect of the electric field on the time spectra is also strongly pressure-dependent: at 1 bar the time spectra recorded with and without an applied field are practically identical, while at higher pressures the decay becomes faster and the peak shifts to shorter times when the field is applied (See Fig. 7). Moreover, the time spectrum which was recorded at 3 bar with the strongest electric field is very similar in shape (peak position and the effective decay rate) to the time spectrum recorded at 1 bar.

3.3. *Suggested physical mechanisms*

According to the literature data, the origin of the UV emission are transitions in CF_4^+ excited ions [5], while the visible emission is due to transitions in CF_3 excited molecules [6]. The

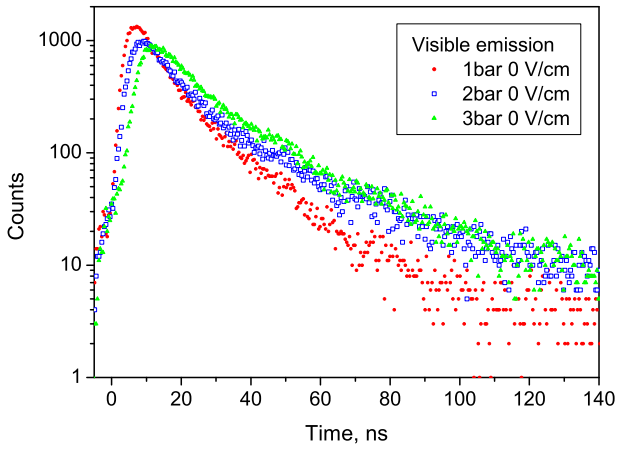

Figure 6: Primary scintillation from CF_4: time spectra of the visible emission (450 - 800 nm) for the gas pressures of 1, 2 and 3 bar.

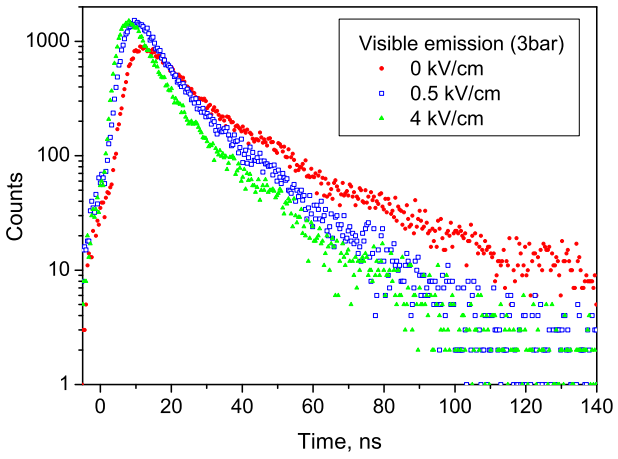

Figure 7: Primary scintillation from CF_4: time spectra of the visible emission (450 - 800 nm) for the gas pressure of 3 bar and several strengths of the applied electric field.

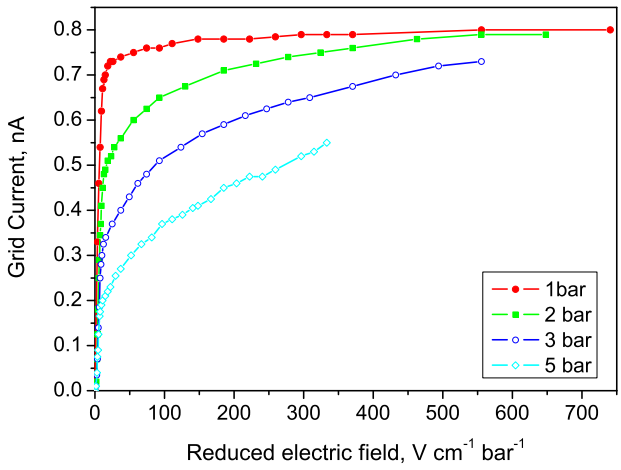

Figure 8: Grid current vs. reduced electric field for several gas pressures.

most likely explanation for the effect of the electric field on the CF_4 primary scintillation involves electron-ion recombination, which is one of the depopulation channels of the excited ions and which appears to be a population channel for the excited CF_3 molecules at high gas pressures. The application of an electric field hinders recombination and, therefore, leads to an increase in the UV emission (less competition for the radiative decay) and to a decrease in the visible emission (less excitation).

At pressures of about 1 bar the role of recombination seems to be very weak: both UV and visible emissions do not show a variation in the spectral shape, in intensity and in the time spectra when the field is changed. This suggests that at these pressures the CF_3 excited states, which emit visible light, are only populated by a direct excitation (and/or by some collisional/radiative channels from other directly excited species). At higher pressures, a substantial part of the excitation is supplied via the recombination channel. However, when a strong field is applied, the recombination channel is essentially "switched off" leaving only the direct excitation. The time spectra of the visible emission support this explanation: as it is shown in Fig. 6, an increase in the gas pressure shifts the peak (an indication of an additional excitation channel) and leads to the appearance of a strong non-exponential "tail", which is a typical signature of a recombinational channel. Also, the application of a relatively strong field at gas pressures of 2 and 3 bar (see Fig. 7) modifies the time spectra in such a way that they become very similar to the spectrum recorded at 1 bar indicating a strong suppression of the recombination channel.

To support the assumption that recombination is weak at 1 bar and strongly increases with the gas pressure, we have recorded the primary ionization current as a function of the applied electric field for several gas pressures. Fig. 8 shows that at 1 bar the current saturates at quite weak fields when the collection efficiency is close to 100%. The current in the saturation agrees well with the value one can calculate using the energy, deposited by the α-particles in the gas per second, and the average energy for the electron-ion pair production. At higher pressures, the current does not reach the saturation, indicating the loss of electrons in recombination processes.

4. Conclusions

The effect of the electric field on the primary scintillation from CF_4 is strongly pressure-dependent: at 1 bar the application of the field has no effect on the spectral profile, on the intensity and on the time spectra, while at higher pressures the field causes an increase in the UV emission and a reduction in the visible emission. At pressures of ~5 bar the application of the field also results in a spectral redistribution of the UV emission. The primary scintillation from CF_4 is very fast (measured effective decay times are $\leq$ 15 ns), therefore, it is well suited for triggering purposes both in drift chambers and in time-projection chambers. The application of the field has practically no effect on the time spectra recorded in the UV range (for all pressures) and in the visible range at ~1 bar. However, the field significantly modifies the time spectra of the visible emission at higher pressures.

5. Acknowledgments

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