Emission properties of low-pressure low-current DC discharge in freons of new generation

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Fluorocarbons, widely used in plasma-based technologies, find applications in the semiconductor industry for etching, cleaning, surface functionalization, deposition of fluorocarbon films, and carbon nanostructures [1,2]. Notably, tetrafluoroethane (HFC-134a) and its low Global Warming Potential (GWP) and low Ozone Depletion Potential (ODP) substitute gas, tetrafluoropropene (HFO-1234yf), serve not only as refrigerants in vehicles and household appliances but also in radiation particle detectors, high and medium voltage gas insulation systems, and polymer film deposition [3,4]. Understanding the electrical characteristics of these fluorocarbons when exposed to electric fields is crucial for developing new applications and enhancing existing ones. Our research focuses on acquiring data on fundamental processes that influence breakdown and gas discharge behavior in fluorocarbon gases under electric fields, aiding in the modeling of gas discharge applications. In our steady-state Townsend experiment (SST), we ignite discharges within a system consisting of two plan-parallel electrodes housed in a quartz tube. The electrodes, with a diameter of 5.4 cm, are positioned 1.1 cm apart. Here, we present a comparison of the results of our DC breakdown measurements for HFC-134a and HFO-1234yf. These results include optical emission spectra, spatially and spectrally resolved distribution of discharge emission, and Paschen curves, providing breakdown voltage and data that could be the basis for modelling and understanding the operation of the discharge.

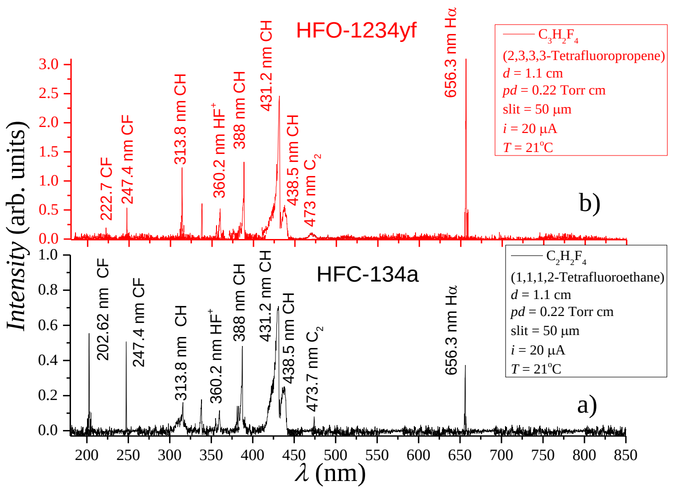

Fig. 1: Optical emission spectra of discharges in a) HFC-134a and b) HFO-1234yf obtained at *pd*=0.22 Torr cm (pressure times electrode distance) and *d*=1.1 cm. The width of the spectrograph slit was 50 µm.

Optical emission spectra of discharges in HFC-134a and HFO-1234yf (as shown in Fig. 1a) and b)) were recorded at low current in the Townsend regime within the 200-900 nm spectral range. Detected emissions include CF, CH, HF^+, C_2, and H_α. These emissions likely arise from excited species resulting from dissociative excitation of the parent molecules [5,6]. Analyzing emission spectra allows identification of possible excited species and proper selection of optical filters for spectrally resolved recordings of axial emission profiles (examples shown in Fig. 2a) and b)). The recorded data includes spatial profiles of total emission within the entire visible spectral range and the spatial distribution of emission in narrow wavelength intervals centered around the most intense lines (at 431 nm and 656 nm). Axial emission profiles, obtained for different *pd* values, illustrate how changes in *E/N* (*pd*) impact the discharge structure and basic processes. Despite operating in the low-current Townsend regime, where space charge density is negligible and the electric field between electrodes is nearly uniform [7], spatial emission peaks in front of the cathode for both freons. This phenomenon is primarily attributed to heavy-particle excitation near the cathode [8]. Additionally, the CH emission (dashed lines in Fig. 2a) and b)) follows the integrated profiles (solid lines), while H_α emission (open circles in Fig. 2a) and b)) exhibits a distinct shape with a more pronounced peak in front of the anode (at these *E/N*). Axial profiles of emitted light in these two freons highlight the substantial contribution of heavy particles to breakdown across a wide range of *pd* values (i.e., the corresponding *E/N* values). In addition to the axial emission profiles, we present the Paschen curves (Fig. 2c)) measured for discharges in HFC-134a and HFO-1234yf, covering a range from 0.05 Torr cm to 1.2 Torr cm. HFO-1234yf has significantly higher breakdown voltages at the same *pd* as compared to HFC-134a.

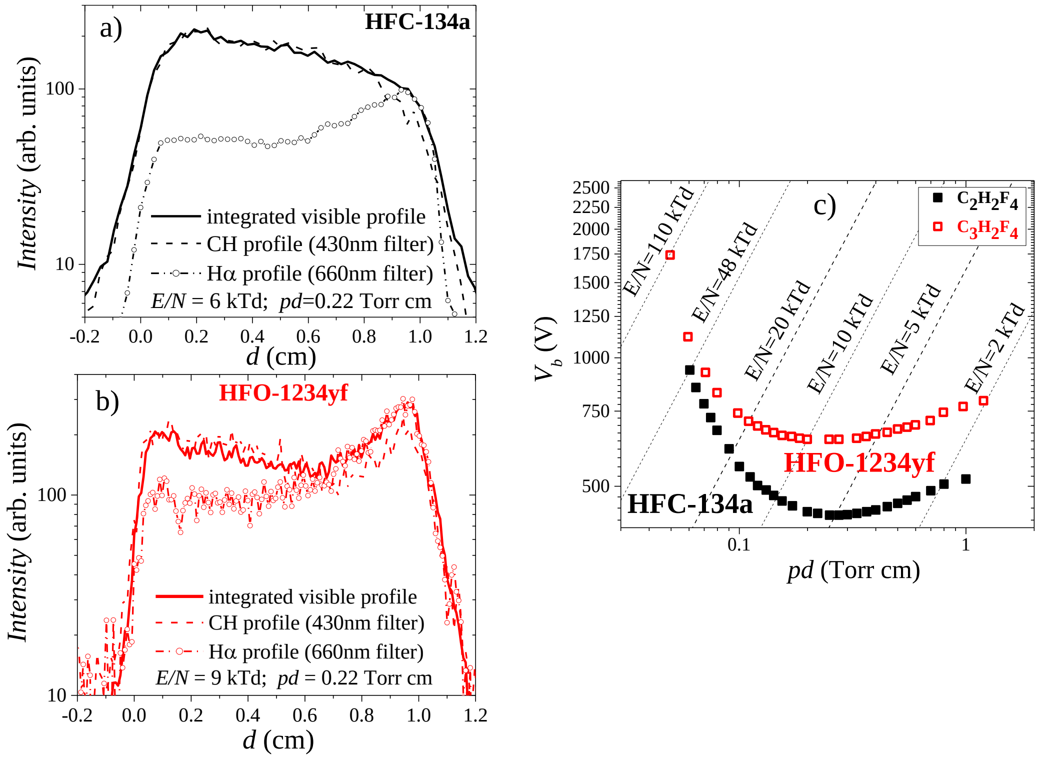

Fig. 2: Axial profiles of emission from discharges in a) HFC-134a and b) HFO-1234yf recorded at *pd*=0.22 Torr cm and *d*=1.1 cm; c) Paschen curves for discharges in HFC-134a and HFO-1234yf at *d*=1.1 cm, at various reduced electric field (*E/N*) indicated by dashed lines [$1\text{Td}=10^{-21}\ \text{Vm}^2$ and 1Torr=133.32 Pa].

Our experimental studies on low-pressure DC discharges in these two freons, combined with optical measurements, enable the identification of elementary processes and provide a complete set of breakdown data. Gaining a better understanding of these processes through data collection and analysis is important for modeling gas plasmas, which can effectively reduce pollutant densities.

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