Ongoing MEMS-based FAIMS-Research for VOC-Detection

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Summary:

Subject of the development is a miniaturized chip-based device that uses ion mobility spectrometry (IMS) for detecting low concentrated volatile organic compounds e. g. in environmental sensing. Focus from preceding development was the fabrication process of the IMS chip with field asymmetric ion mobility (FAIMS) as ion filter. The required electronics were combined with the IMS chip and a demonstrator system has been developed. The measured spectra of exemplary ketones (acetone, 2-hexanone) show typical behavior. This proof of function enables ongoing development towards specific applications.

Keywords: ion mobility spectrometry, volatile organic compounds, miniaturized, MEMS, chip device

Introduction

A wide range of applications in environmental sensing makes use of the detection of volatile organic compounds (VOCs). VOCs are harmful even in low ppb concentrations. This results in an urgent need for portable devices at the point of interest. VOCs can also be used for diagnosis of diseases. It is known that infections have an impact on the VOC footprint of breath gas, urine, blood and saliva. A fast and easy-to-use point of care device for diagnosis or monitoring would open up a large market. Low concentrated analyte gases, varying conditions and interfering substances result in a demanding development of an easy-to-use system. The current development focuses on a miniaturized sensor element that enables a selective detection of common ketones.

FAIMS-Chip as Miniaturized IMS

Ion mobility spectrometry (IMS) is an established method to detect gaseous analytes like VOCs under ambient conditions [1]. Therefore, IMS allows an easy integration into a measurement system. Ionized molecules are filtered according to their specific ion mobility K. This value depends on the ion mass, collision cross section and background gas. The ion trajectories and hence the filtering is done using electric fields in which the ions move with the drift velocity v_D

$$v_D = K\,E. \tag{1}$$

With regard to a miniaturized sensor component that can be manufactured by means of micro-technologies, common time of flight ion filters are unsuitable. In contrast, field asymmetric ion mobility (FAIMS) shows a good downscaling. High electrical field strengths are used, which have an impact on cluster and collision processes and hence the ion mobility K(E) itself. In addition, special shaped signals are applied to the filter with high field and low field conditions. Thus, the ions move on specific ion trajectories and only ions with an appropriate K(E)-behavior pass the ion filter and reach the ion detector. An additional compensation voltage CV changes the filter parameters and enables other ions to reach the detector. A CV sweep leads to a single spectrum with peaks that represents one kind of ion. An additional sweep of the maximum field strength E_{Filter} lead to FAIMS typical spectra. The CV shift of the peak maximum is characteristic for the ion [1].

Demonstrator System and Measurements

The developed demonstrator uses a miniaturized IMS Chip with FAIMS ion filter, that is already described in [2] and [3], and also comprises necessary electronic components. This new system according to Fig. 1 allows measurements of spectra and hence the proof of function of the IMS chip. An UV discharge lamp was used for atmospheric pressure photoionization (APPI).

Exemplary measurements according to Fig. 2 show the expected and typical FAIMS spectra, namely a decrease of peak intensity with increasing field strength E_{Filter} and changes in the location of the peak maxima on the compensation voltage axis. Differences of these two peak

properties can be observed in the spectra for acetone and 2-hexanone.
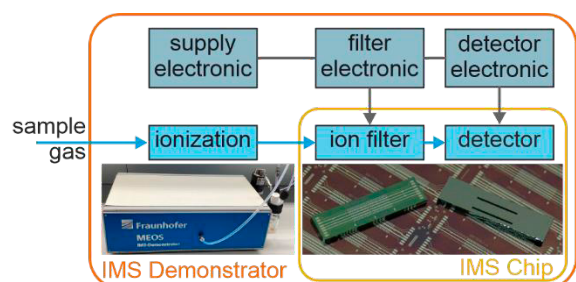

Fig. 1. Schematic overview of the developed IMS demonstrator with IMS chip that includes ion filter and detector, ionization source and basic electronic components

The CV shift of acetone firstly becomes positive, then negative for increasing dispersion voltages. For 2-hexanone the measurements show a negative shift of the CV. The observed trends agree with results from literature [4]. However, the absolute CV displacement is lower than expected.
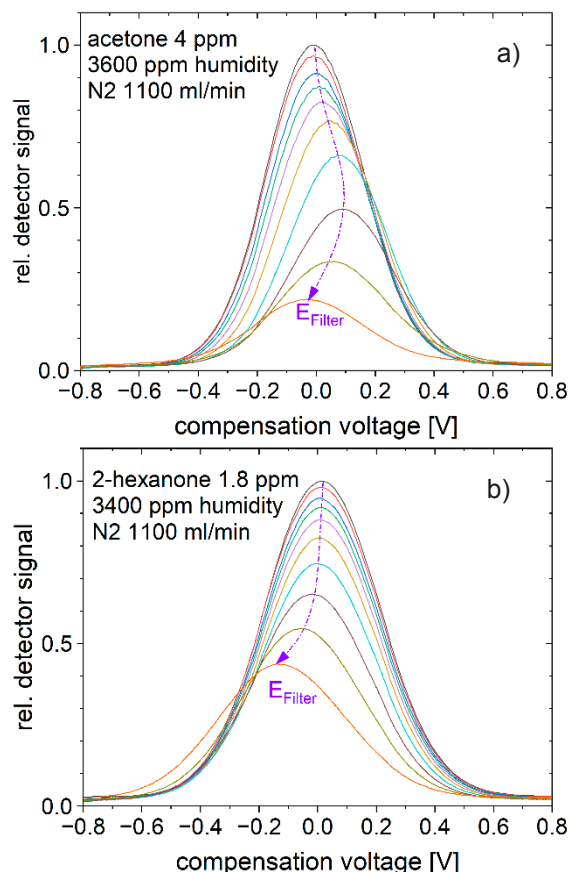

Fig. 2. Typical FAIMS spectra with a) positive CV shift and b) negative CV shift of the peak position with increasing filter field strength E_{Filter}.

According to [5], high humidity and atmospheric pressure chemical ionization (APCI) lead to water clusters $H^+(H_2O)_m$ that are not related to the analyte molecule. FAIMS spectra show a pronounced displacement towards positive CV due to strong clustering effect. Measurements with

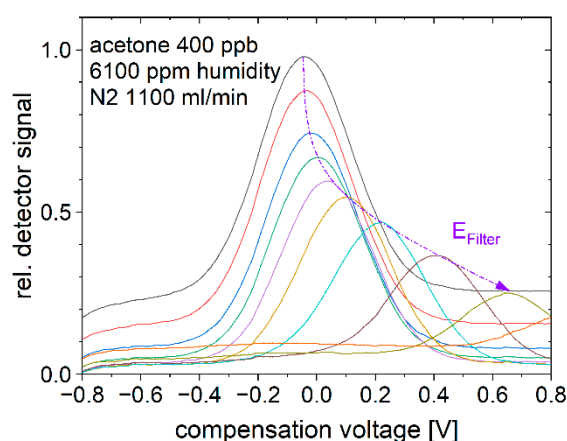the given setup and APPI show the same effect. (Fig. 3)

Fig. 3. Typical FAIMS spectra with a relatively large positive CV shift at high humidity conditions (approx. 22% rel. humidity at 22°C)

Summary and Outlook

Measurements were performed with the developed demonstrator and the integrated IMS chip with FAIMS ion filter. Results are in agreement with comparable FAIMS data. This provides the basic proof of function. Further focus must be placed on understanding and accurately analyzing the spectra obtained. This can be done in combination with mass spectrometry and other laboratory methods. The deeper knowledge about the measurements and dependencies are a basis for addressing new applications.

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