A journey into DMS/FAIMS technology

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Differential Mobility Spectrometry (DMS), often referred to as High Field Asymmetric Waveform Ion Mobility Spectrometry (FAIMS), is a mature technology for gas phase ion separation. It is a technique that has been shown to dramatically improve or rival a number of mainstream ion detection and identification technologies operated at ambient pressure. The enabling aspect of the differential mobility technique is that ions have field-dependent mobility when exposed to strong electric fields above 10,000 V/cm. Mason and Daniel were among the first to describe this phenomenon in their classical book: “The Mobility and Diffusion of Ions in Gases”, published in 1973. DMS is based on the non-linear field dependence of the coefficient of mobility in strong electric fields and thus it is fundamentally different from conventional low field techniques such as time-of-flight Ion Mobility Spectrometry (IMS). The method to harness the differential mobility approach for ion separation was first proposed in Soviet Union in the 1980’s by M. Gorshkov. Later Igor Buryakov and his colleagues were the first to develop a practical implementation of DMS and they first described their findings for Western scientists via the journal publication, “*Separation of ions according to their mobility in a strong alternating current electric field,*” by I.A. Buryakov, E.V. Krylov, A.L. Makas, E.G. Nazarov, V.V. Pervukhin, and U.Kh. Rasulev, *Sov. Tech. Phys. Lett.* 17 (6), 1991, p 446. Over the years, this technology has been referred to by many names, such as: Non-linear Drift Spectrometry, Field Ion Spectrometry (FIS), Radio Frequency Ion Mobility Spectrometry (RF IMS), FAIMS, Differential Ion Mobility Spectrometry (DIMS), and DMS.

Over the course of its development, the geometry of the separation cell (based on a pair of analytical electrodes) used for DMS has diverged down two different pathways: (1) a pair of flat planar electrodes and (2) a pair of cylindrical (or curved) electrodes. These geometry differences are important and result in different analytical performances of the DMS/FAIM devices. Analysis and comparison of these two approaches can be found in recent publications concerning to DMS technology.

The DMS technology was transferred to the West in the mid-nineties in two ways. The cylindrical version moved from Novosibirsk to Mine Safety Appliances (MSA) Company in Pittsburg, where the first commercial prototype of the cylindrical design was built [B. Carnahan, S. Day, V. Kouznetsov, A. Tarassov, *Development and applications of transverse field compensation ion mobility spectrometer*, in: *Proceeding of an Fourth International Workshop on IMS, Cambridge, UK, 1995*]. Later, Roger Guevremont’s scientific team adapted this cell for use as an ion pre-filter for Atmospheric Pressure Ionization Mass Spectrometry and started to call this system FAIMS (R.W. Purves, R. Guevremont, *Anal. Chem.* 71 (1999) 2346–2357). The FAIMS system was commercialized by newly formed Ionalytics Corporation in Canada (2000). In 2005, Ionalytics was purchased by ThermoFisher Corporation (now called Thermo Scientific). Thermo Scientific’s current product is called a FAIMS interface, which works in combination with the Heated Electrospray Ionization Source (HESI) and Atmospheric Pressure Chemical Ionization (APCI) ion probes on their triple stage quadrupole mass spectrometer.

Differential mobility sensors with planar electrodes were developed in parallel at two research sites in USSR (Tashkent and Novosibirsk) in the late 1980’s [I.A. Buryakov, E.V. Krylov, E.G. Nazarov, U.Kh. Rasulev *Int. J. Mass Spectrom. Ion Process.* 128 (1993) 143–148]. This technology was brought in 1996 to Prof. Gary Eiceman’s laboratory at New Mexico State University (NMSU), which is one of lead center

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in ions mobility based technology investigation and developments. The first prototype of a micromachined DMS sensor was built by the Charles Stark Draper Laboratory in Cambridge, Massachusetts by Raanan Miller and Erkin Nazarov, as a part of Draper funded collaboration with NMSU. During this project, the planar geometry evolved further in terms of a better fundamental understanding of the DMS phenomena, miniaturization and providing new analytical applications of the technology. In addition to these scientific investigations, the first prototypes of compact gas analyzers and detectors for use with Gas Chromatography (GC) were designed and built. Later, these prototypes were used for the founding of a new spin-off company called Sionex Corporation. Around that time, the technology started to be referred in literature as DMS, in order to be more relevant to the basic physical principles of operation.

In the 10 year period between 2001 and 2010, Sionex Corporation (following an OEM business model) provided numerous DMS sensors & electronics kits to companies that specialize in the production of analytical systems for the detection and identification the traces of hazardous chemicals in complex mixtures. As a result, the following analytical instruments were developed around the DMS sensor: (a) Varian CP 4900 microGC, for the detection mercaptans and sulfur compounds in environmental samples, (b) ThermoFisher EGIS™ Defender for simultaneous detection of explosives & narcotics in transportation security, (c) Chemring's handheld JUNO™ for the trace detection and identification of chemical warfare agents and toxic industrial chemicals, (d) Hamilton Sundstrand's Tandem Mobility Spectrometer for chemical warfare agent and toxic industrial chemical monitoring, (e) TechnoScan Systems Inc. built a prototype of analyzer *TSI-3000*, which can be used for detection threats in cargo (explosives & narcotics), (g) Draper Laboratory's microAnalyzer, a GC-DMS system that combines sophisticated pre-concentration, flash thermal desorption, GC temperature ramping, and DMS separation and detection in a compact, portable and field-deployable package, (h) The R&D group at AB Sciex worked closely with the Sionex team to develop a planar DMS-MS system that was commercialized in 2011 under the trade name Selexion™ (see details T.R. Covey, B.B. Schneider et al., in Current Trends in Mass Spectrometry, supplement to LCGC/Spectroscopy, July 2012, www.spectroscopyonline.com).

Since its introduction, DMS/FAIMS technology has been adopted by various researchers resulting in multiple instru-

mentation designs by several academic laboratories, government institutions, and instrumentation companies. This has led to further refinement and commercialization of both planar and cylindrical geometries during the last decade. Significant contributions to the development of DMS/FAIMS have been made by the following people and their research teams: Dr. Richard's Smith and Alexandre Shvartsburg (Pacific Northwest National Laboratory), Dr. Jun Xu (Oak Ridge National Laboratory), Prof. Paul Vouros (Northeastern University), Prof. Paul Thomas (Loughborough University, UK), Prof. Richard Yost (University of Florida), Prof. Gary Glish (University of North Carolina at Chapel Hill), and Dr. Ashley Wilks (Owlstone Inc.).

As described in this short historical overview, we can see that this technology made huge progress from its beginnings in the late 1990's. This progress is a result of the work of scientific research leaders, who are responsible for the progress and transformation of DMS/FAIMS technology. In the early stages, this method was considered as interesting physical phenomena for the separation of ion species at ambient pressure. Now, this method has been exploited to enable a new class of powerful analytical instruments focused on varied applications. A notable advantage of this family of gas analyzers is the amenability for miniaturization and operation in harsh environments, which has resulted in the attraction of more and more interest. Evidence of this is the dramatically increasing number of scientist and application developers using this technology in their professional activity. While in the 1990's only sporadic publications concerning DMS/FAIMS were found, currently this technology is discussed in broad scientific forums including special sections at annual conferences such as Pittcon, ASMS, ISIMS, workshops and so forth. The amount of reviews, monographs, and manuscripts, including high ranking journals, also increases each year.

Offered for your attention thirteen manuscripts in this special issue: "Differential Ion Mobility Spectrometry (DMS/FAIMS) - Instrumentation and Applications" reports recent results concerning the theoretical investigation, computer modeling, method development and new applications.

Sincerely,
Dr. Erkinjon Nazarov.