NANOENGINEERING CORPORATION

...maneuvering matter on a molecular scale...

Yale University

SEADM

An IMS with a resolution of 1,000 and parts per trillion sensitivity for ambient vapors

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Workshop Presentation

New Methods for Explosive Detection for Aviation Security

Northeastern University, Boston MA - October 22, 2013

DHS Center of Excellence for Awareness and Localization of Explosives-Related Threats (ALERT)

Tandem DMA - CCD

The DMA² –CCD System Concept offers potential capabilities necessary to address 21st Century Aviation Security Challenges

1. **General Purpose – *ion mobility measurement***
2. **High Resolution (≥ 1000) – *500 analytes***
3. **High Sensitivity (≤ parts-per-trillion) – *plastic explosives***
4. **High Sample Flow Rate (>10 L/min) – *direct vapor sampling***
5. **Low Cost – *No High Vacuum***
6. **Related applications in Chem-Bio Threat Detection**

Mass Spec Performance – IMS Cost – Sniffer Dog Aspiration

Outline

An IMS with a resolution of 1,000 and parts per trillion sensitivity for ambient vapor

1. Detection of Airborne Trace Volatiles
2. DMA-DMA-CCD Technology for Ambient Vapor Detection
3. Development Plans / Related Applications
4. Commercialization, Collaboration and Sponsorship
5. Conclusions and Acknowledgements

Airborne Vapor Sensors

Definition:

Point Sensors detect with rapid response the presence of threat in immediate vicinity usually by sampling and detecting volatile vapors of explosives and chemical weapons

Key Examples:

1. Canine Olfaction (Sniffer Dogs)
2. Mass Spectrometers
3. Ion Mobility Spectrometers

Performance Criteria –Threat Sensors

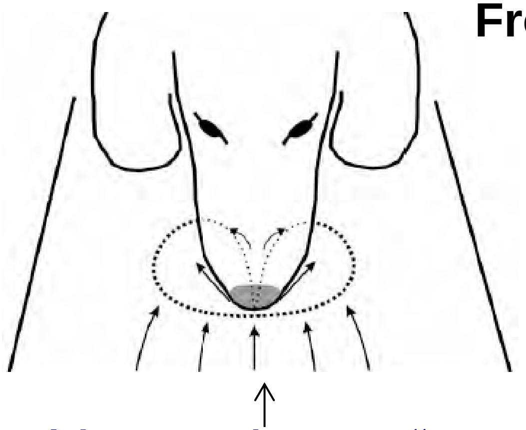
1. General Purpose – Detects all threat analytes
   - 500-analyte capability desired by DHS
2. Power of Discrimination – Resolution
   - Distinguish threat “A” from interferant “B”
   - Affects occurrence of false positives
3. Limits of Detection – Sensitivity
   - Threshold analyte concentration needed to trip sensor
   - Affects occurrence of false negatives
4. Response Time – Sound alarm
   - ~ 2 Seconds in aviation security
   - Affects passenger throughput
5. Low Costs – Capital and Operating

Sniffer Dogs

"About 2,000 of these working [sniffer] dogs confront danger alongside U.S. soldiers, largely in the Middle East. **Able to detect scents up to a third of a mile away**, **many sniff for explosives in Iraq**." [emphasis added]

Washington Post, August 12, 2007

- Inhaled air enters the upper airway (*dorsal meatus)* of the dog's nose
- Exhaled air is vectored down and sideways by the midlateral slit
- The dog's nostril is thus a variable-geometry inlet and exhaust flow diverter



From: "*Airborne Trace Sampling: Lessons from the Dog's Nose"*
Prof Gary Settles
Penn State University
TED Workshop 2010

Unidirectional jet aspirates "smells" into nose

Flow rate: Q ~ 10 – 100 L/min

Mass Spectrometers

Pro: "Gold Standard" for general analytical chemistry

- High mass resolution (2000 – 10,000)
- High sensitivity (~ parts-per-quadrillion)

Con: High vacuum inherently limits practicality in airports

- High-vac. pumps are complex, costly, fragile, maintenance-intensive
- Low sample flow rates (< 1 L/ min)
    - higher air flow must be balanced with much bigger pumps

Ion Mobility Spectrometer

Pro: "Practical" - in use in airports

- General Purpose
- Lower costs – capital and operating
  - *no high vacuum*
- Rapid Response (seconds)
- Good sensitivity (parts-per-billion)

Con: Inadequate for Emerging Threats

- Low Mobility Resolution – Cannot distinguish 500-analytes
- Low Flow Rate (≤ 0.1 L/min)
- Sensitivity - Inadequate for Direct Airborne Vapor Sampling
  - *swabbing required*

Data Points

RDX – room temp vapor pressure: < 10 parts-per trillion
Sarin – deadly at parts-per-billion concentration
HMEs –precursors ; interferants

Tandem DMA²-CCD Sensor – System Concept

Pro: Potential to Address All 21st Century Threats

- General Purpose – measures mobility
- *Promises* lower costs – *no high vacuum*
- High Mobility Resolution (≥ 1000) – 500 analytes
- Rapid Response (seconds)
- Ultra-sensitive (≤ parts-per-trillion)
- High sample flow rates (>10 L/min)
- Direct airborne vapor sampling (?) – *no swabbing*

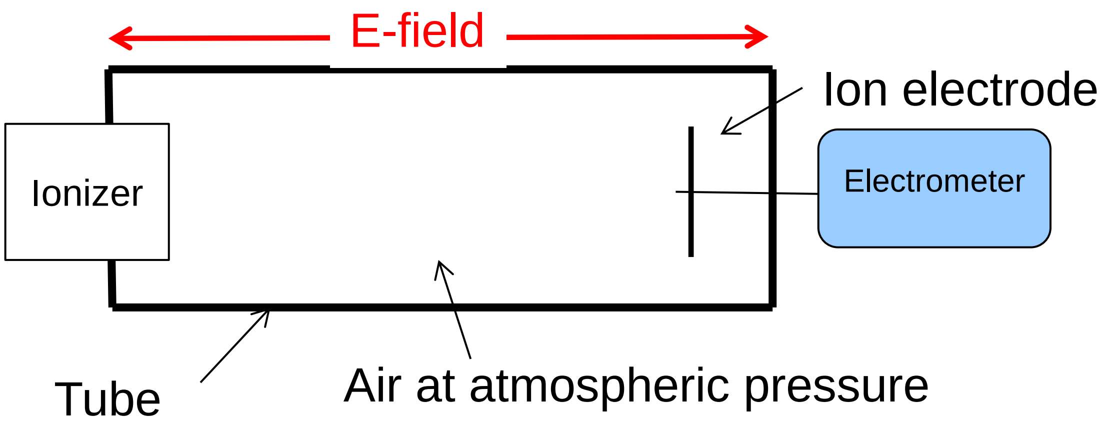
Con: Embryonic - Developmental

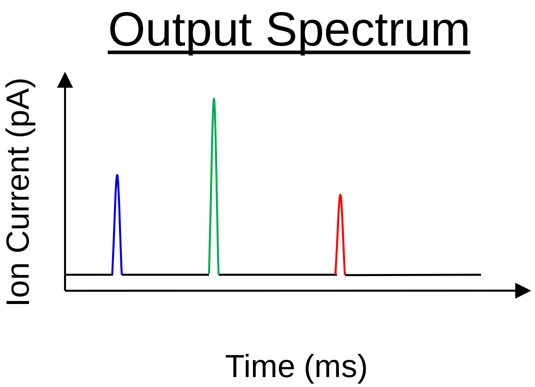
- Needs development, testing and field trials
- Based on existing science demonstrated at Yale, SEADM
- Relies on proven components from SEADM, NEC and suppliers

Mass Spec performance - IMS cost – Sniffer -Dog aspiration

Conventional IMS

Drift-tube IMS : Time-of-Flight Measurement

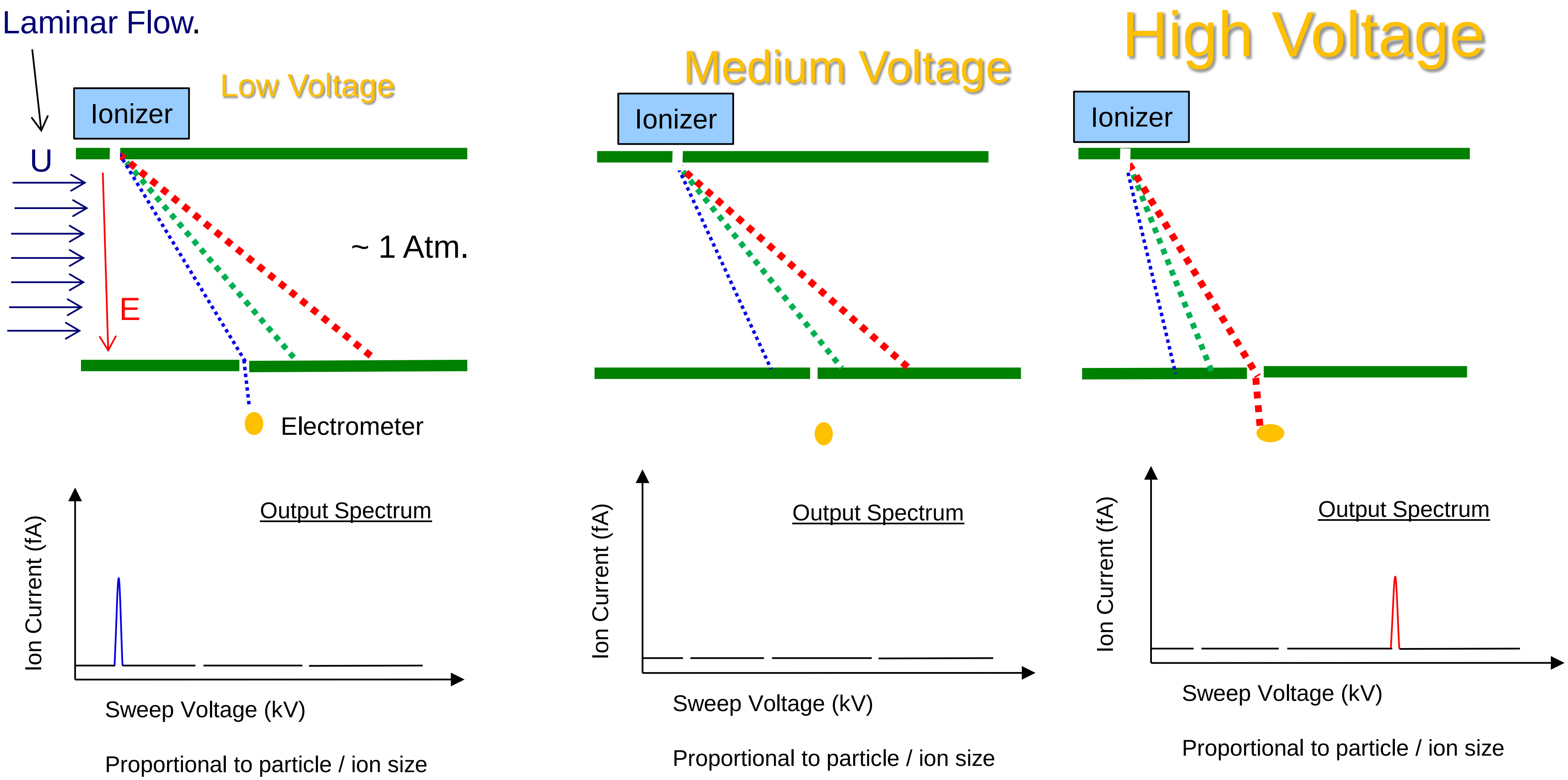




Drift time:	~20 ms
Duty cycle:	~1% - major limitation!
Detection Limits:	parts-per-billion!
Output Spectra:	Ion current (I) vs. elapsed time-of-flight (t)

Conventional DMA

Differential Mobility Analyzer



Balance of System

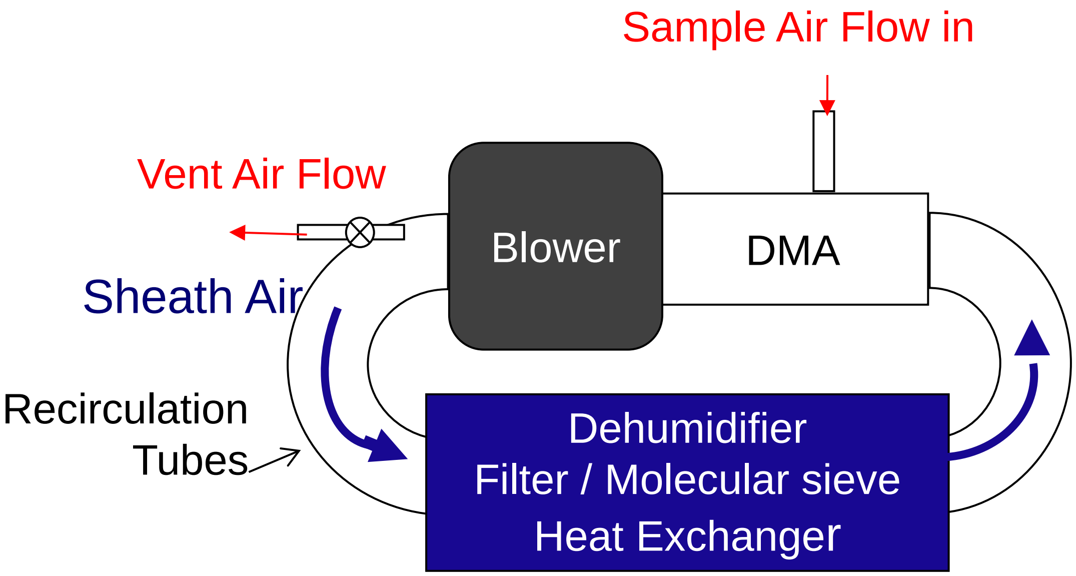
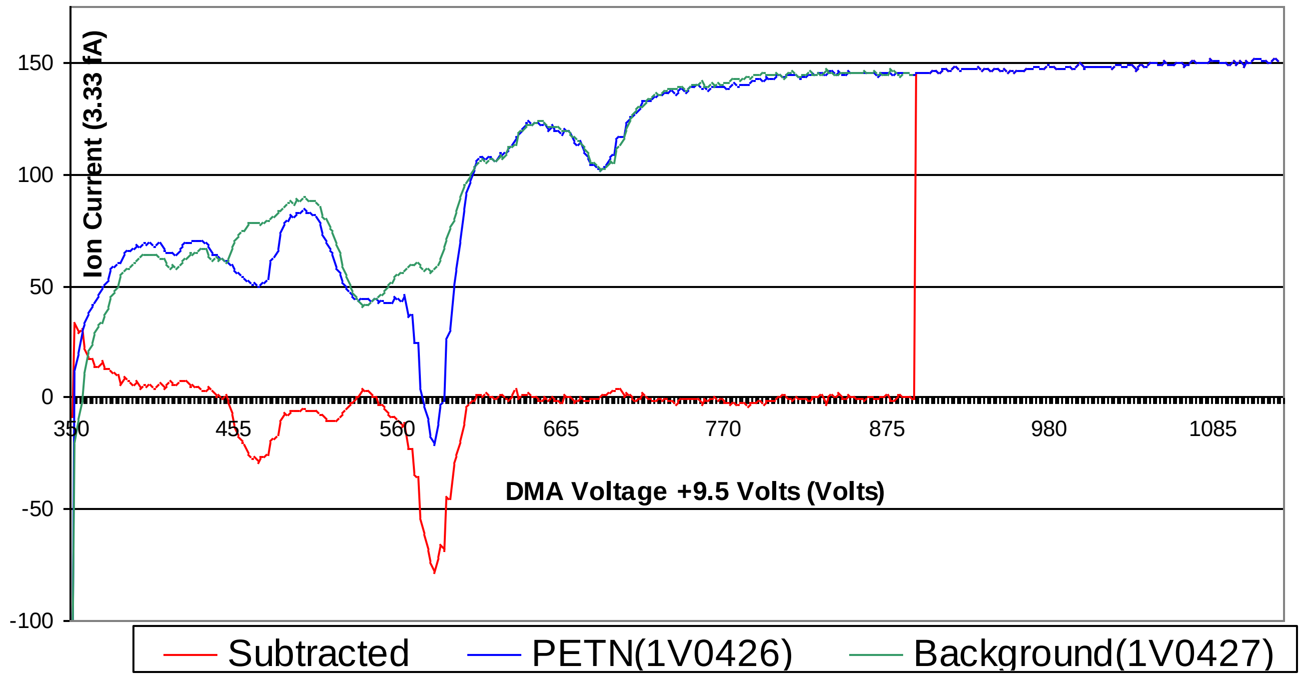


Photo: System Prototype
(Scissors for scale)

Plastic Explosive

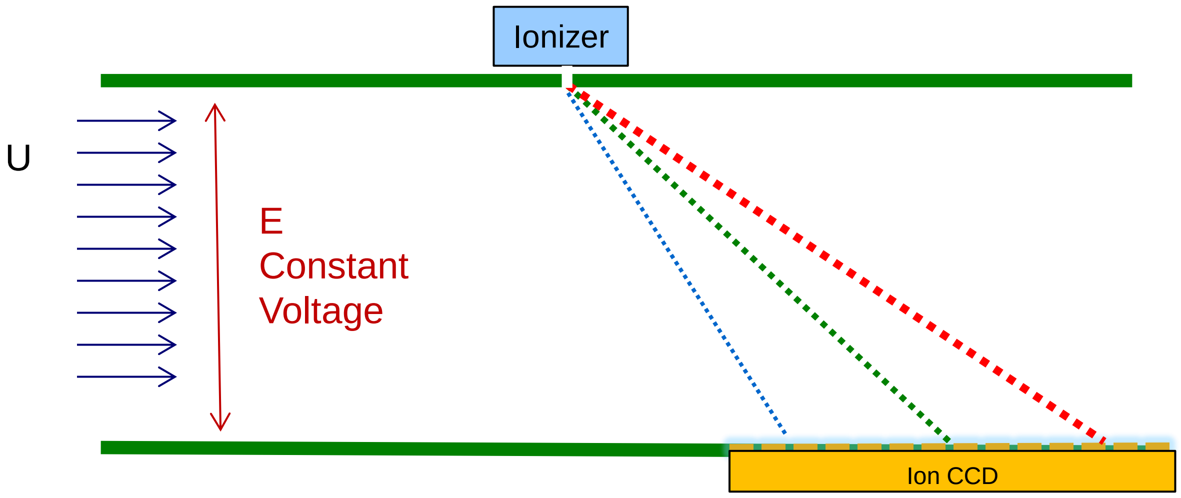
Detection of PETN at Room Temperature



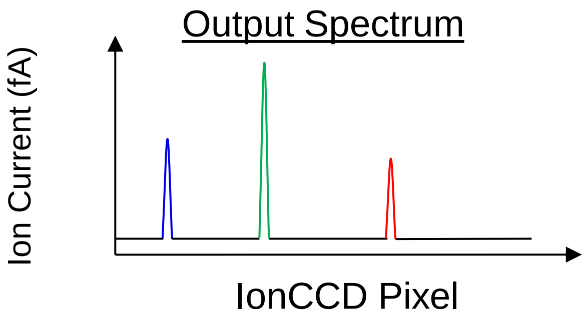
PETN Vapor Pressure* = 18 ppt @ 25 C

*B.C. Dionne, D.P. Rounbehler, E.K. Achter, J.R. Hobbs and D.H. Fine, *Vapor Pressure of Explosives* J. of Energetic Materials 4 447-472 (1986)

DMA + CCD



100% Duty Cycle



Planar DMA

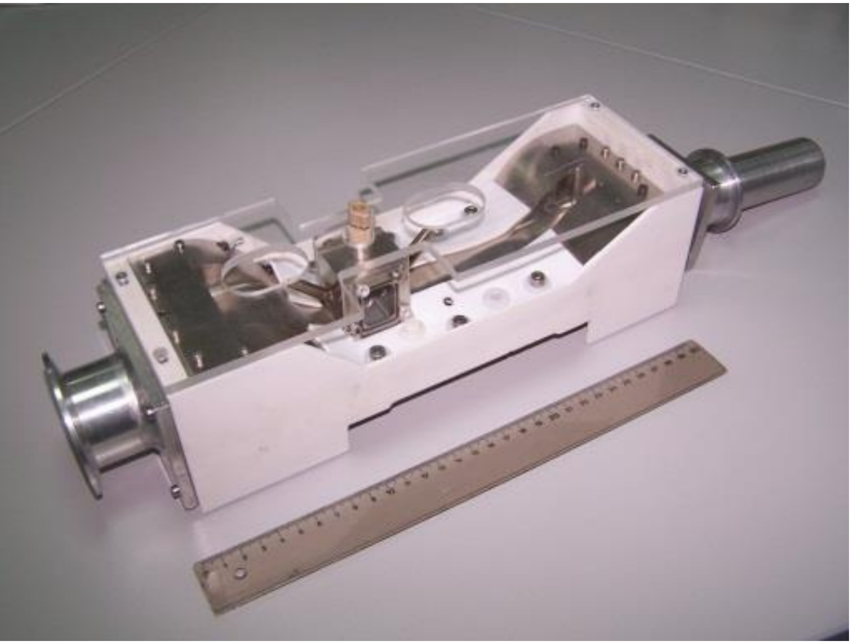
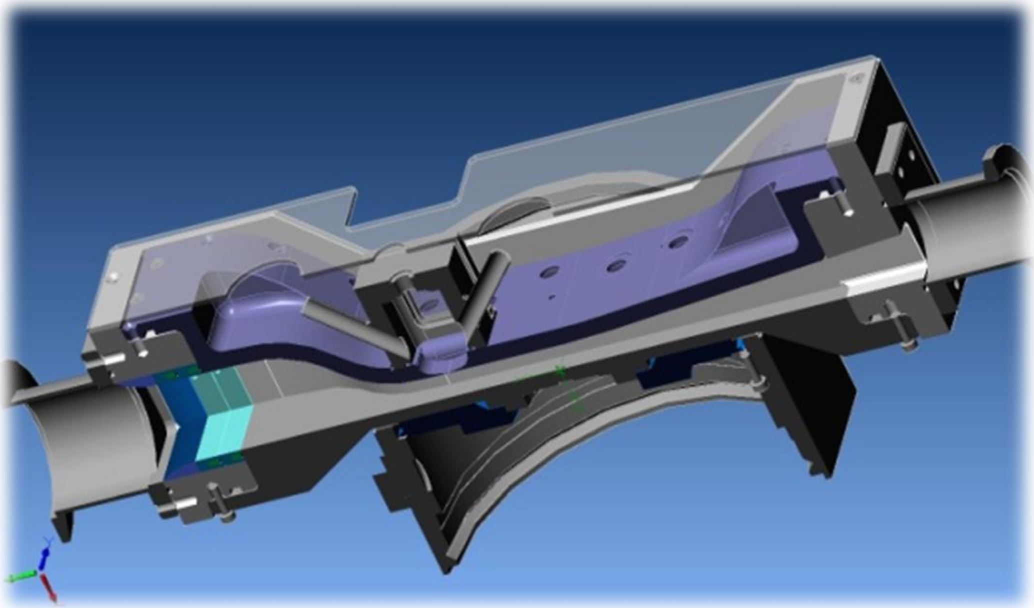


Photo: High Resolution DMA – Yale Univ.
12-inch ruler for scale



CAD drawing shows internal flow-channels

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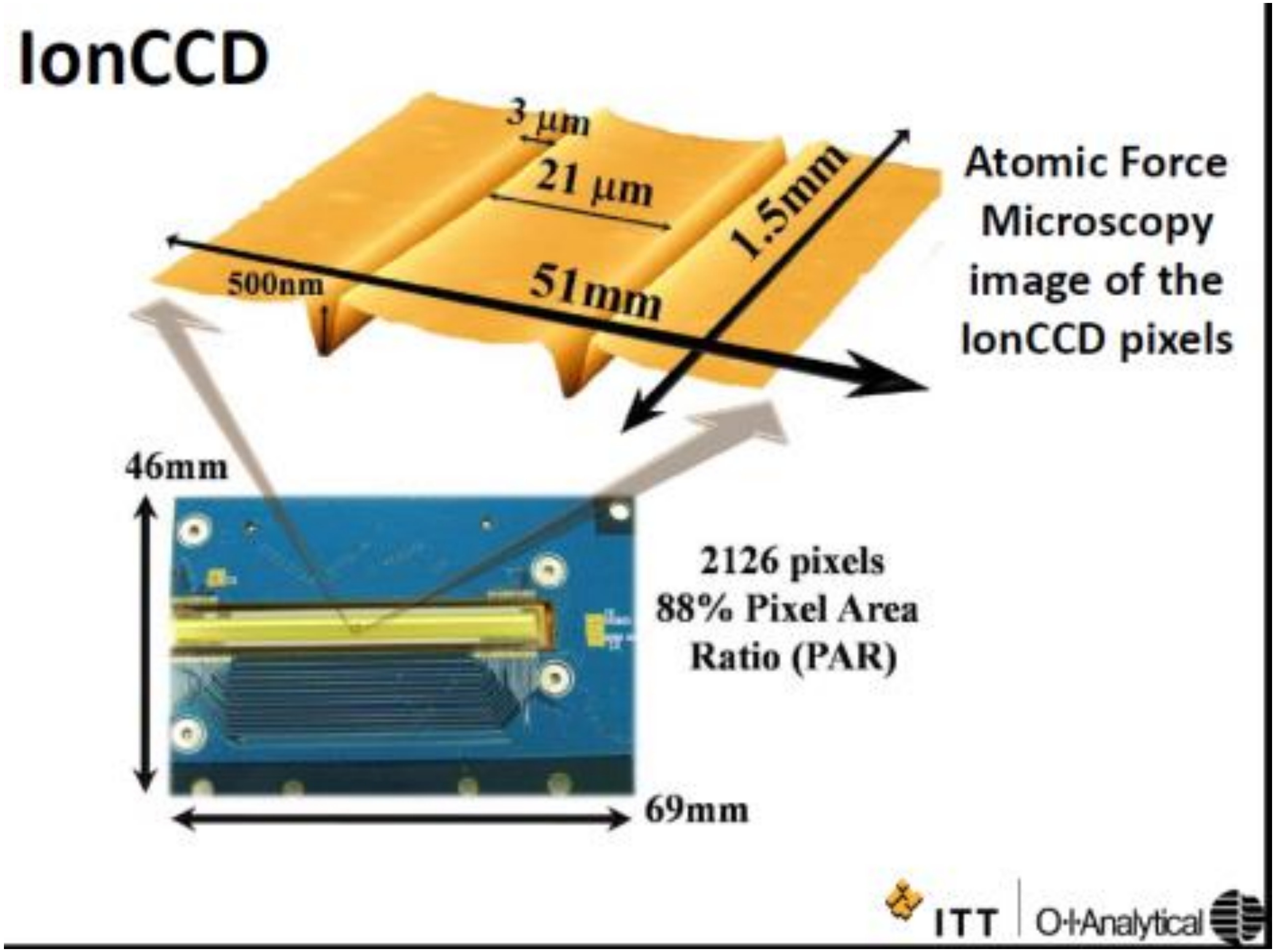
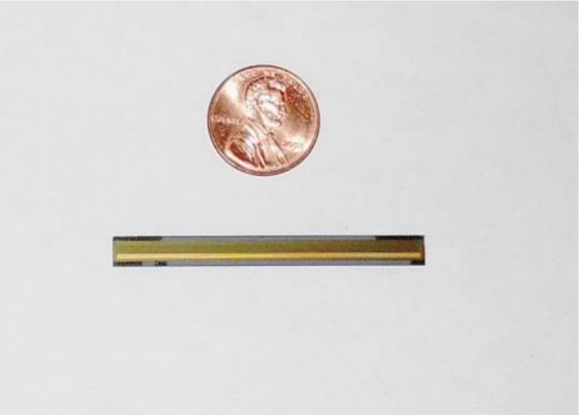
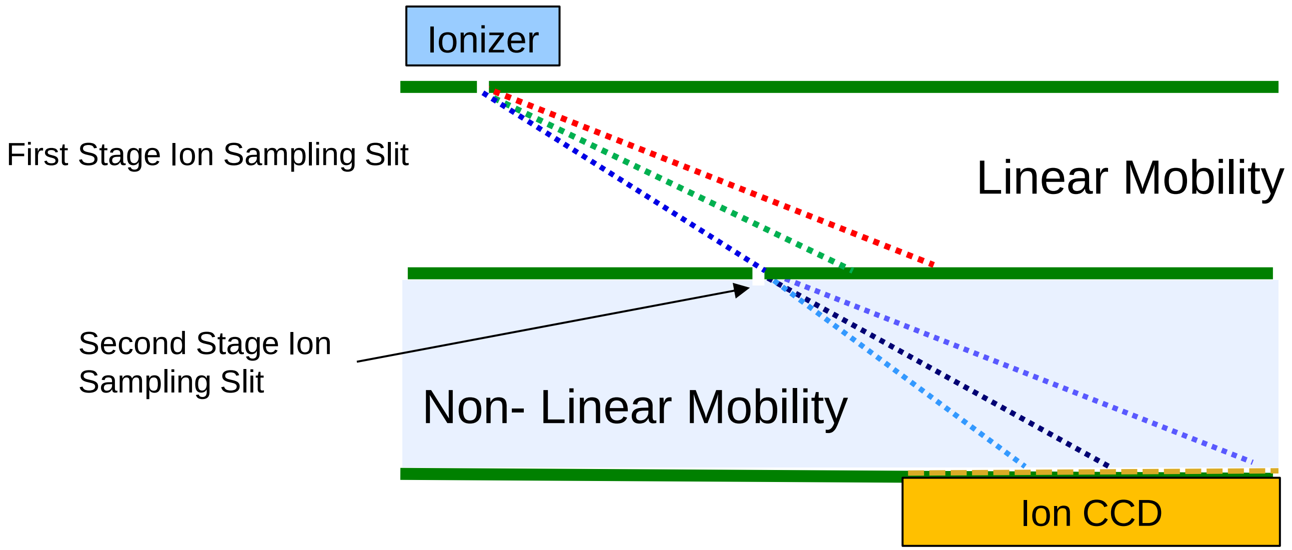
Ion CCD Detector





- < 1000 charges per pixel to detect with S/N of 3 (1 sec. integration)
- Dynamic range: 10^7

Tandem DMA – DMA : Cascade



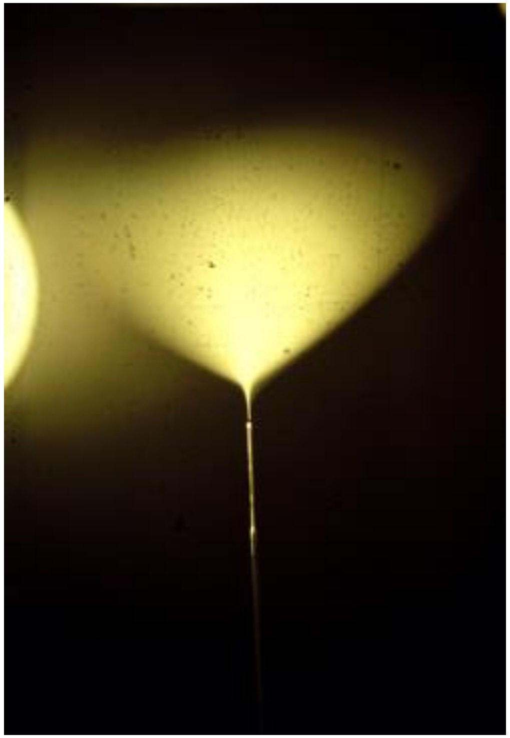
Anticipated Performance

- resolution ≥ 1000
- sensitivity ≤ parts per trillion

Ionizer

Secondary Electro-Spray Ionization (SESI)

Glass Capillary Tip
In-situ micrograph
OD=360 µm: ID=40µm



Dense Droplet Mist
From Taylor Cone
Back-lit Photograph

Development Plans

DMA is a Platform Technology

1. ***Explosives***
2. ***Chemical Agents***
3. ***Biological Threats (No reagents)***

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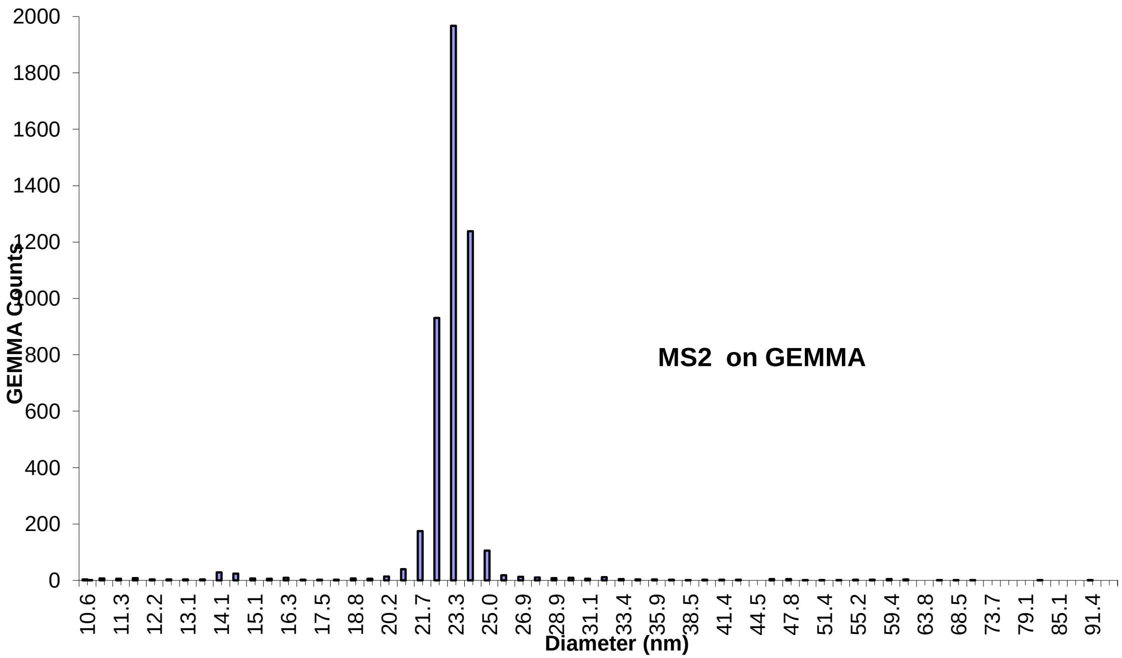
Rapid Virus Screening

ES-DMA for virus detection

Cooperative R&D with US Army Edgewood Chem-Bio Ctr.



* *Frost & Sullivan report predicts high growth in $billion / yr markets for "molecular diagnostics" targeting these viruses*.

Table 1: Human Viruses

Virus Name	Size (nm)
polio	23
rhinovirus	30
norovirus	35
hepatitis	38
encephalitis	42
dengue	45
west Nile	53
papilloma	55
rotavirus	75
hantavirus	80
rubella	85
Epstein-Barr	101
adenovirus	100
influenza	120
SARS coronvirus	130
respiratory syncytial	151
HIV	182
herpes	200
smallpox	220
And more...	

Commercialization

NEC is an SBIR Company

NEC has secured key patents and patent rights w/ SEADM

NEC, Yale and SEADM have developed 30-page proprietary white-paper detailing our technology development plans

Barrier to commercialization: Lack of R&D and Exploratory Engineering Support.

We welcome:

- **Sponsorship**
- **Collaboration**
- **Development partners**
- **Commercialization partners**
- **Potential customers**
- **Investors**

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Mass Spec Performance – IMS Cost – Sniffer Dog Aspiration

Tandem DMA – CCD Concept

- **Based on solid science**
- **Relies on proven components**
- **Candidate for rapid development**
- **Suited for widespread deployment**

Acknowledgements

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