A Coded Aperture Magnetic Sector Mass Spectrometer

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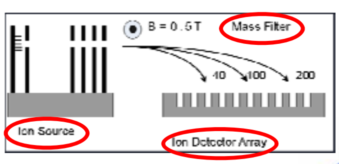
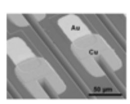
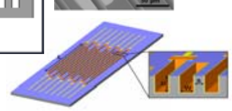
Motivation: Miniaturizing a Mass Spectrometer

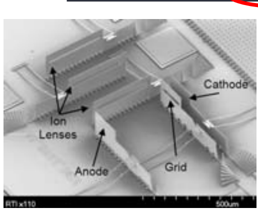
- Goals
  - Reduce size, cost, and power consumption in mass spectrometry by two orders of magnitude
- Applications
  - Space: Mars and lunar rover
  - Medical: Analyze blood chemistry
  - Military/Security: Chemical/biological hazard alert
  - Environmental: Sense pollutants

CAMMS System Components







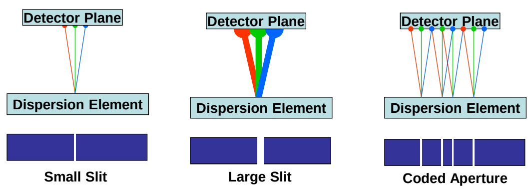


- MEMS electron ionization source
  - CNT field emission electron source
- Microfabricated ion detector array
- Permanent magnet mass filter
- Coded Aperture at Ion Source Exit for improved SNR
- For more information see poster by Erich Radauscher (presented by Charles Parker

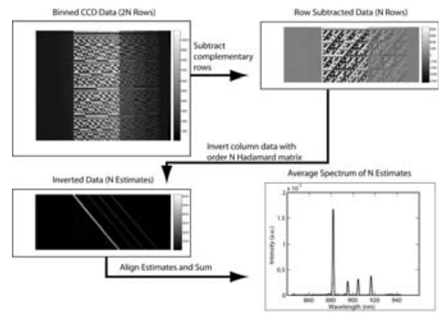
Coded Aperture Motivation and Presentation Outline

- Miniaturized systems suffer from reduced signal intensity
  - [E.R. Badman, R.G. Cooks, Anal. Chem. 72 (2000) 3291.]
- Aperture Coding has been used in Optical Spectroscopy to dramatically boost Signal to Noise Ratios
  - [David J. Brady, Optical Imaging and Spectroscopy Wiley-OSA, 2009]
  - [M. Gehm, S. McCain, N. Pitsianis, D. Brady, P. Potuluri, and M. Sullivan, "Static two-dimensional aperture coding for multimodal, multiplex spectroscopy," Appl. Opt. 45, 2965-2974 (2006).]
- Presentation Outline
  - Aperture Coding in Optical Spectroscopy
  - Aperture Coding in Mass Spectroscopy and Ion Optics
  - Poof of Concept Test Bed Design and Component Focus
  - Experimental Results Showing 15x Intensity Improvement
  - Summary, Conclusions, and Future Work

Aperture Coding in Light Optics

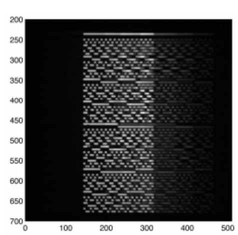


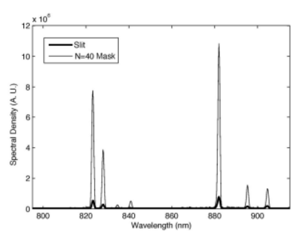
Aperture Coding in Light Optics



M. Gehm, S. McCain, N. Pitsianis, D. Brady, P. Potuluri, and M. Sullivan, "Static two-dimensional aperture coding for multimodal, multiplex spectroscopy," Appl. Opt. 45, 2965-2974 (2006).

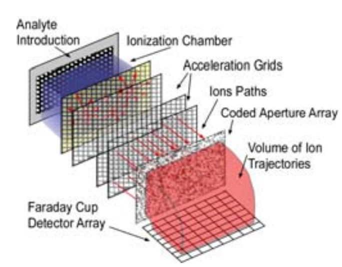
Aperture Coding in Light Optics





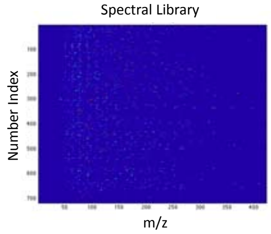
M. Gehm, S. McCain, N. Pitsianis, D. Brady, P. Potuluri, and M. Sullivan, "Static two-dimensional aperture coding for multimodal, multiplex spectroscopy," Appl. Opt. 45, 2965-2974 (2006).

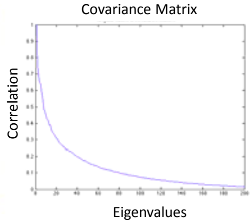
Coding Magnetic Sector Instruments



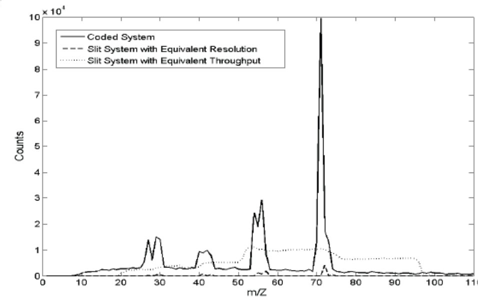
[1] C.B. Parker, D.J. Brady, J.T. Glass, and M.E. Gehm, Coded mass spectroscopy, US Patent 7,399,957 (2008).

Mass Spectral Library Compressibility

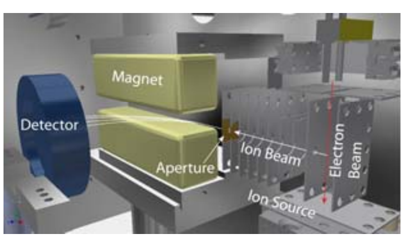




Predicted Coded Aperture Merit

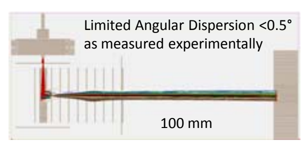


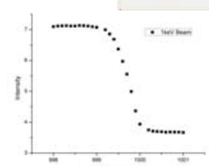
Proof Of Concept Test Chamber

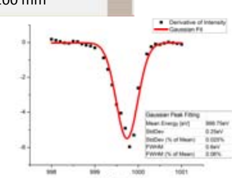


1. Custom built EI source from Kimball Physics stainless steel eV parts
2. 0.45 T bar magnet and yoke from Dexter Magnetics
3. 40 mm 10 micron pitch multichannel plate with phosphor screen detector from Beam Imaging systems

Neir Type EI Ion Source



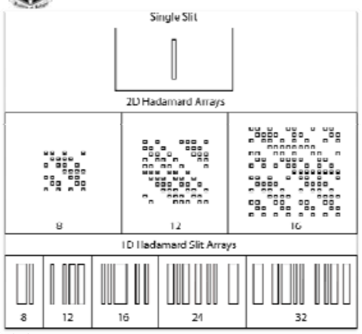


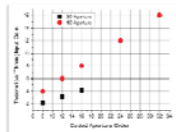


Beam Energy = 999.8 ± 0.3 eV

<0.3% Dispersion

Hadamard Coded Apertures





Hadamard patterns were chosen due to their ease in incorporation into the forward model

The apertures were fabricated via deep reactive ion etching (DRIE) of 250 micron thick silicon wafers with feature sizes down to 25 microns

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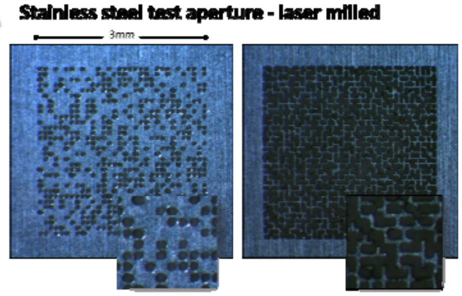
Aperture Fabrication-1

Stainless steel test aperture - laser milled



- 50 µm features intended to be squares (~50 µm LASER diameter)
- Minimal feature sizes recommended to be the same as metal plate thickness

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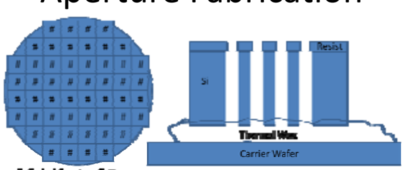
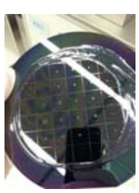
Aperture Fabrication





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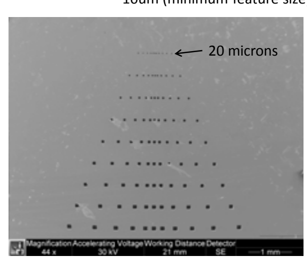
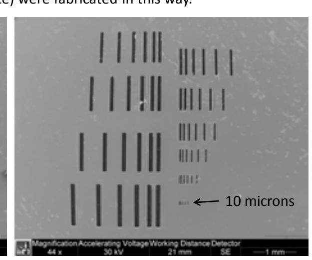
Aperture Fabrication

Thru holes and slits as small as
10um (minimum feature size) were fabricated in this way.





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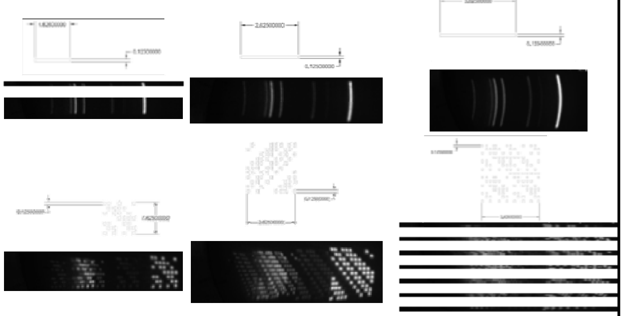
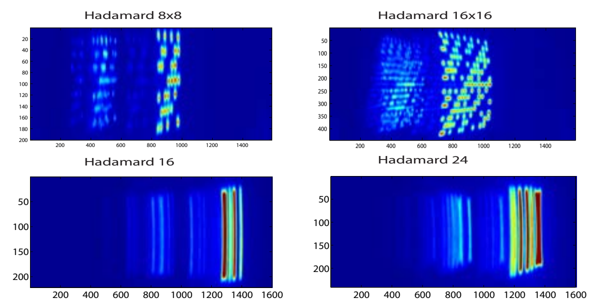
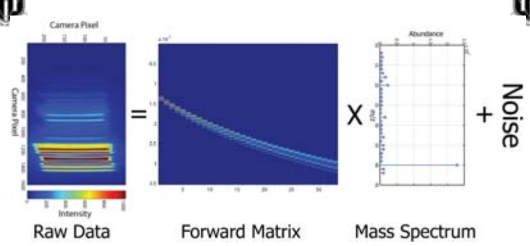
Aperture Fabrication



Experimental Raw Data



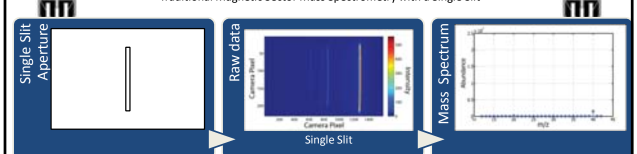
How Coding Works



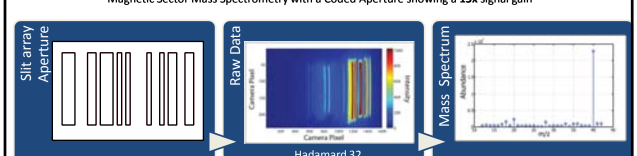
- The inverse of the Forward Matrix allows transformation of the raw data into the mass spectrum.
- The Forward Matrix is derived from the physics of the system and geometry of the coded aperture
- For additional information see poster by Evan Chen (presented by Zach Russell)

Coded Aperture 15x Gain

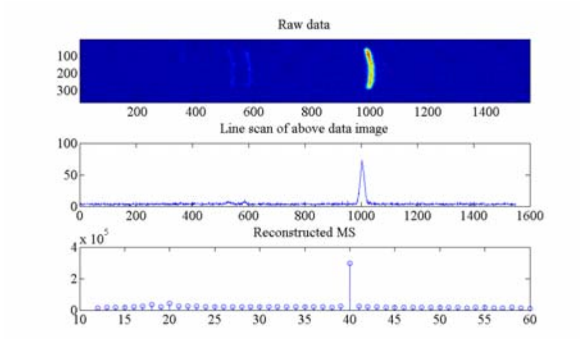
Traditional Magnetic Sector Mass Spectrometry with a Single Slit



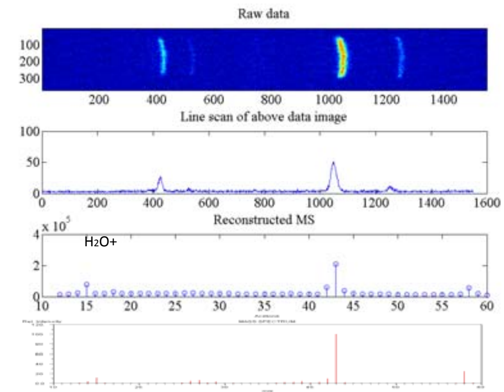
Magnetic Sector Mass Spectrometry with a Coded Aperture showing a **15x** signal gain



Slit-Argon

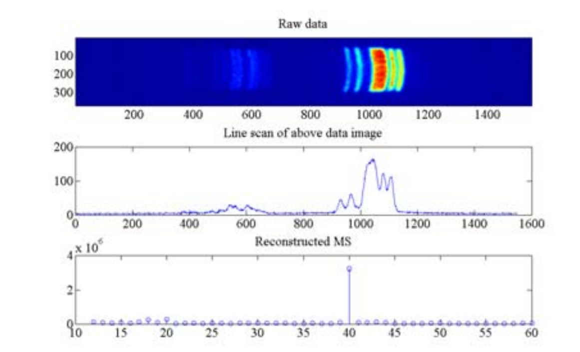


Slit-Acetone

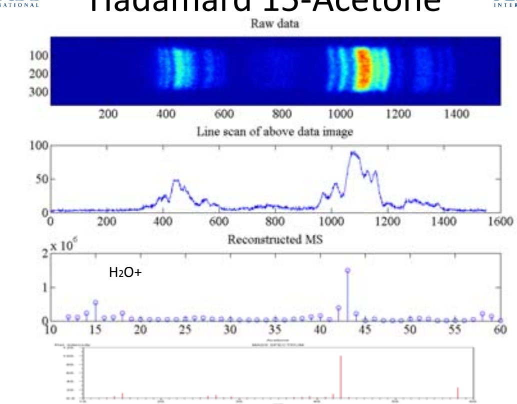


NIST Mass Spec Data Center, S.E. Stein, director, ""Mass Spectra"" in **NIST Chemistry WebBook, NIST Standard Reference Database Number 69**, Eds. P.J. Linstrom and W.G. Mallard, National Institute of Standards and Technology, Gaithersburg MD, 20899, http://webbook.nist.gov, (retrieved September 4, 2013).

Hadamard 15-Argon



Hadamard 15-Acetone



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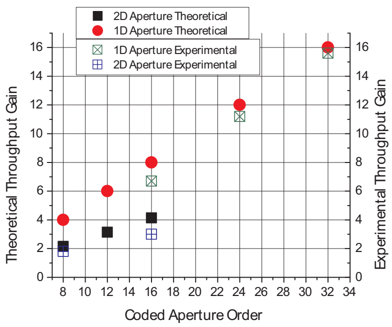
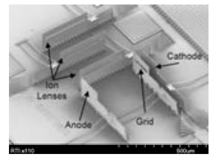
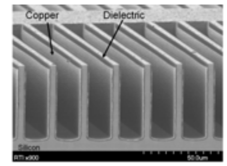
Gain vs Aperture Complexity



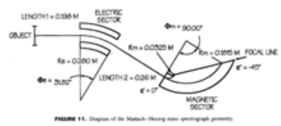
Future Work

Micro Component Integration





Mattauch Herzog Geometry



Burgoyne TW, Hieftje GM. 1996. An introduction to ion optics for the mass spectrograph. *Mass Spectrom Rev* **15**: 241–259.

Cycloid Geometry

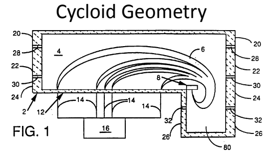


FIG. 1

Kurzweg, Lutz; 1994 Feb. 17. Cycloidal mass spectrometer and ioniser for use therein. European Patent Application number 98106485.0

Thank You!
Questions?

Acknowledgements

- Department of Homeland Security, Science and Technology Directorate Contract HSHQDC-11–C-00082
- National Science Foundation, ECCS Award 0801942
- RTI International Fellows Program
- Mitch Wells, Ryan Danell, Shane Di Dona, & Erich Radauscher

NIST Mass Spec Data Center, S.E. Stein, director, ""Mass Spectra"" in **NIST Chemistry WebBook, NIST Standard Reference Database Number 69**, Eds. P.J. Linstrom and W.G. Mallard, National Institute of Standards and Technology, Gaithersburg MD, 20899, http://webbook.nist.gov, (retrieved September 4, 2013).

Abstract (for reference only)

- The ultimate goal of this project is to develop a coded aperture microfabricated mass spectrometer (CAMMS) [1]. This instrument concept is based on integrating aperture coding [2], used primarily in optical spectroscopy, with a carbon nanotube-based field emission source, charged particle optics on a microfabricated MEMS (MicroElectroMechanical Systems) platform and a permanent magnet magnetic sector. MEMS technology has been shown to be an excellent platform for the development of miniaturized charged particle devices [3]. However, decreased throughput and small sample sizes in microfabricated instruments are expected to lead to diminished performance. To minimize this degradation in performance we are investigating the principles of multi-aperture coding [1]. Use of coded apertures can eliminate the historical trade-off between resolution and signal intensity in a mass spectrometer. Our current focus is proof of concept work on the application of coded apertures to ion optics in a testbed with a traditional thermal electron ionization ion source. The charged particle simulation program SIMION is utilized to inform system design as well as to establish appropriate working conditions for electrostatic lens systems. This presentation will include: (i) the microfabricated system concept, (ii) the coded aperture-testbed design and optimization, and (iii) results from Hadamard coded apertures that have been shown to provide a 15x increase in throughput as compared to single slits without sacrificing mass resolution.