Development of Organic Molecule Imaging at the Louisiana Accelerator Center (OMILAC)

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Outline

Organic molecule imaging using MeV SIMS

- Why image organic molecules in an MeV ion microprobe?
- How does MeV-SIMS work?
- A Second generation MeV SIMS instrument
- Practical details.
  - ToF-reflectron
  - Low noise Si p-i-n detectors
  - MCU-based electronics
- Where are we and where are we going?
Why MeV-SIMS?

- MeV ion microbeams have unique multi-modal imaging capabilities
- Inorganic materials have been the main study area
- Organic materials which include animals, plants, polymers, energy materials are largely ignored.
- Co-imaging of elements and specific biomolecules with structural features will give new science.

Co-imaging examples: µ-PIXE

1st generation MeV-SIMS

MCP stop detector

Linear ToF

Objective aperture

Collimator

Sample + 10 kV

$^{12}\text{C}^{4+}$
MeV-SIMS

OMILAC 2nd generation MeV-SIMS

Molecular ions ejected into backwards $2\pi$ sr.

- Ejection energy distribution width is $\sim 20$ eV.
- The wide energy span limits the resolution for linear ToF spectrometers according to:

$$\frac{dt}{dE} = -L \sqrt{\frac{M}{2E^{3/2}}}$$
Molecular ion Acceleration stage

Linear and Reflectron ToF dispersion

\[ E = qeV_{acc} \]

**Linear ToF**

\[ t = L \sqrt{\frac{M}{2E}} \]

\[ \frac{dt}{dE} = -L \sqrt{\frac{M}{2E^{3/2}}} \]

**Reflectron ToF**

\[ t_R = \frac{L_R}{U_mqe} \sqrt{2ME} \]

\[ \frac{dt_R}{dE} = -\frac{L_R}{U_mqe} \sqrt{\frac{2M}{E}} \]

\[ T = t + t_R; \quad \frac{dT}{dE} = 0; \quad U_mqe \rightarrow E \]

\[ L_R = \frac{L}{4} \]
DIPLOMA Linear + Reflectron telescope

\[ L = L_{L1} + L_{L2} \]  

DIPLOMA ToF Reflectron

Photo: H.J. Whitlow

MeV ion microbeam

MeV ion microprobe for imaging at the Louisiana Accelerator Center

From: H.J. Whitlow (unpublished work)
MeV ion microbeam at the Louisiana Accelerator Center

Magnetic lenses

OMILAC Mass spectrometer

Beam Line

Analysis chamber

MeV ion microprobe electronics

Photo: H.J. Whitlow
Problem: Fast timing was difficult with standard Hamamatsu p-i-n diodes (S1223-01) due to ground loops and pickup.

- Need for noise-free signals from DC to about 1 GHz.
- Chamber was electrically isolated from beamline.
- Adequate for energy spectroscopy with time constants $\tau_{RC} \sim 5 \, \mu s$.
- Not adequate for fast timing with few ns $\tau_{RC}$
Si - Start detector - II

- Kapton® tape
- Pre-amplifier ground
- Analysis chamber ground
OMILAC electronics configuration

- Fast HV switch
- Beam blanker
- Objective aperture
- Collimator
- ToF reflectron
- 12C4+ beam
- Si p-i-n diode start detector
- Gate pulse generator
- Multi-stop TAC
- Sequential DAC
- STM32 MCU
- Mass pulses
- OM-1000e ADCs
- OM DAQ3
- Trigger
- Spectroscopy Amplifier
- Direct-STIM signal
- Const. Fact. Disc.

- Mass pulses: 0 V to ±HV
- Gate pulse generator: 0 V to 3.3 V and 0 V to -120 V
- Objective aperture: 0 V
- Beam blanker: 0 V
- Collimator: 0 V
- ToF reflectron: ±HV
- 12C4+ beam: 0 V
- Si p-i-n diode start detector: 0 V
Challenges:

- Need to measure time differences up to ~50 µs with 15 ns resolution.
- DAQ system accepts only analogue pulses easily.
- Molecular fragmentation gives multiple mass pulses from a single start pulse.
- Conventional TACs cannot handle multiple stops.
- Provide TTL blanking pulse to fast beam-blanker.
Why multi-stop Time to Amplitude Converter

To measure high mass signals you need to veto light ( = faster fragments) because they make single stop TAC blind.

Problem: Molecular fragmentation patterns carry important information
ARM-based 32-bit MCU approach

Beyond the Arduino....

- Low-Cost
- Lower learning threshold than FPGAs
- Dual fast comparators
- 50 – 480 MHz clock rates
- 1 MHz DAC for output
- Memory-mapped hardware device registers
- Full-speed USB
- Well developed integrated development systems
- Devices STM32G4, STM32H7, ESP32, PIC32CM MCUs

STM32G4 MCU on STM Nucleo32 prototype board.

Photo: H.J. Whitlow
ARM MCUs - "super-fast CAMAC on a chip"
MCU implementation of TAC/TDC-MCB

Start pulse -> Comparator -> Event

Stop pulse -> Comparator -> Event

Discriminator level

170 MHz clock

64-bit counter

DMA

Time stamp buffer

Beam blanking pulse

Analog pulses to OM-DAQ

To control PC

DAC

Sorting process

Multi channel buffer

FS-USB-VCP
Concluding remarks

- MeV-SIMS has great potential at MeV ion microbeam facilities because it allows co-imaging with µ-PIXE, RBS, off-axis and Direct-STIM, opening up the possibility to study a wide range of biomedical, environmental, geological, materials and even space science topics.
- A 2nd generation MeV-SIMS is under construction at the Louisiana Accelerator Center with \( M/\Delta M \approx 2000 \).
- The combination of a linear and reflectron ToF sections will cancel the energy broadening from sputter ejection.
- Efficiency maximised by measuring start pulses with a Si detector.
- ARM-based 32-buit MCU’s are sufficiently fast for pulse spectroscopy processing and could be developed to a flexible replacement of NIM electronics.
- CoViD-19 has been a real pain for the project....
Thank You for attending today’s presentation