Hydrocarbon polymers

- About our group
  - Mailing List
  - LinkedIn Group
  - ASMS website
  - Sanibel/Asilomar Proposal
  - Informal online meetings

- Talk: Robert B. (Chip) Cody, JEOL USA

- Talk: Anthony (Tony) Gies, Dow

- Thierry’s short demo (time permitted)

- Open discussion & wrap-up
Join our mailing list!
LinkedIn group

https://www.linkedin.com/groups/4009861/
Evening Workshop
June 7, 2023

Polymeric Materials
Coordinators: Thierry Fouquet (Bausch & Lomb) and Anthony Gies (Dow Chemical Company)
For more from this interest group (presentation slides, etc.) click here.

ASMS website
https://www.asms.org/member-center/interest-groups/polymeric-materials
Sanibel / Asilomar

- Submitted August 2022
- Polymeric Materials

Sanibel/Asilomar proposal:
Mass Spectrometry of Synthetic Polymers and Related Materials: Present Capabilities and Future Potential

Rationale

The discovery of soft ionization techniques, in particular matrix-assisted laser desorption ionization (MALDI) and electrospray ionization (ESI), and the development of mass spectrometry (MS) instrumentation has made it possible to monitor the mass and, thus, the structure and/or elucidate chemical composition of complex mixtures. The advancement of mass spectrometry (MS) instrumentation, provides not only improved quantitation but also the molecular level elucidation using advanced matrices and approaches, utilizing tandem mass spectrometry (MS/MS) and various derivatives of these technologies.

Sunday

8:30 - 9:30 am
Session 6: Fate of polymeric materials and global pollution
- Talk 1: polymer degradation, recycling, and global microplastic pollution
  Proposed speaker: A. McNeil, Michigan State, MI
- Talk 2: PFAS
  Proposed speaker: L. Field, Oregon State University, OR

9:45 - 10:45 am
Session 7: excipients and surfactants
- Talk 1: polymeric surfactants
  Proposed speaker: J. Hsu, AbbVie, MI
- Talk 2: polymeric excipients
  Proposed speaker: K. Yang, FDA

11:00 am - 12:00 pm
Keynote lecture 7: Bio-inspired polymers, biomimetics and natural polymers
The final keynote session will focus on the interface of polymers and biological systems, including potential discussion of applications such as drug or gene delivery, imaging agents, anti-biofouling, or polymer-protein biomimetics
Proposed speaker: K. Busscher, Texas A&M, TX, or B. Stemmler, University of Florida, FL, or A. Salizzoni, University of Washington, WA

12:30 - 1:00 pm
General discussion about the future of the field and closing remarks
Proposed speakers: J. Hsu, T. Fouquet, C. Wendemuth
Sanibel / Asilomar

- Submitted August 2022
- Polymeric Materials

Sanibel/Asilomar proposal:
Mass Spectrometry of Synthetic Polymers and Related Materials:
Present Capabilities and Future Potential

Rationale

The discovery of soft ionization techniques, in particular matrix-assisted laser desorption/ionization (MALDI) and electrospray ionization (ESI), and/or continuous groups of mass spectrometers (MS) advancements in mass spectrometry (MS/MS) architecture, provides the molecular level approaches, utilizing.

Proposal for ASMS Sanibel Conference
Mass spectrometry and its role in characterizing the life cycle of plastics.

Ruth Morfil-Vega (Shimadzu Scientific Instruments), Domia Barcelo (CIC; ICRA).

We propose a Sanibel conference focused on the role of mass spectrometry in the analysis of plastics throughout their life cycle, from raw material manufacturing to their presence in the environment as macro-, micro-, and nanoplastics. Plastic play a key role in modern life, with many consumer and industrial products being made of some type of plastic polymer. Because we rely on these materials, it is critical that stakeholders from all types of plastic polymer.

We believe that the proposed topic will be of interest to several communities/interest groups within ASMS membership (environmental, exposomics, polymers...). If the proposal is accepted, the Polymers Interest Group expressed interest in helping with the organization of a future conference focusing on this topic. This will provide a chance to strengthen collaboration between two minority groups within ASMS's current membership, as well as foster knowledge sharing amongst key stakeholders involved in defining the future of the science of plastics.
About our informal online meetings...

- 19 people: I will be happy to attend whenever possible
- 5 people: I would be OK to present (results, issues, papers...)
- 1 person: Let's meet at the ASMS only
Talks

- Hydrocarbon polymers analyzed with 3 mass spectrometers and 6 ionization methods
  Robert B. (Chip) Cody, JEOL USA, Inc.

- New Approaches for Examining Complex Polyolefin Mixtures
  Anthony Gies, Dow
Are you familiar with hydrocarbon polymer analysis?
Hydrocarbon polymers analyzed with 3 mass spectrometers and 6 ionization methods

Robert B. (Chip) Cody, JEOL USA, Inc.
Polymer Interest Group Workshop
ASMS 2023
Outline

This talk:

1. MALDI TOF/TOF for polystyrene
2. Pyrolysis: GC-MS and Evolved Gas Analysis (EGA)
   - Electron ionization
   - Chemical ionization
   - Photoionization
   - Field ionization
3. Detailed GC-MS analysis of syndiotactic, isotactic, atactic polypropylenes
4. Thermal desorption and pyrolysis/DART

Also possible: TGA/MS (e.g. Netzsch)
Data analysis resources for polymers

- **FSearch** (Frontier Lab): Pyrolysis GC-MS data analysis with searchable compound and pyrogram database
- **msRepeatFinder** (JEOL): mass defect analysis with easy GUI and good graphics
- **Mass Mountaineer** (massmountaineer.com, Me): Many functions for analysis of centroided mass spectra including mass defect analysis and chemometrics. *Most of the slides in my talk.*
- “**Kendo**” (Thierry, DOI: 10.13140/RG.2.2.16742.45124): standalone freeware for mass defect analysis
- **Polymerix, Investigator** (Sierra Analytics): sophisticated tools for analysis of homopolymer and copolymer composition and deconvolution of homopolymer and copolymer mixtures. *Tony will show examples in his talk.*
GC-MS Qualitative analysis (knowns and unknowns)

- **msFineAnalysis AI (JEOL):** Qualitative GC-MS data analysis making use of ALL the available information from soft and hard ionization, accurate mass and isotope data, and retention index matching. Variance analysis for two-sample comparison.
  - **NEW:** AI-assisted structure analysis with an in-silico database for the 100-million chemical structures in PubChem and a support AI to predict the presence/absence of substructures. **I’ll discuss in this talk.**

- **Hybrid Search (NIST):** EI spectrum plus molecular weight. Finds compounds with similar structures and shows where critical fragments shift. Use with NIST MS Interpreter to determine structures of unknowns.

- **Know-It-All Informatics (Wiley):** Adaptive search is a similar function to NIST hybrid search. Can integrate data from non-MS analysis (NMR, FTIR, Raman, etc.)
Pyrolysis - GC/MS Data Book of Synthetic Polymers
Pyrograms, Thermograms and MS of Pyrolyzates
1st Edition - August 2, 2011

Authors: Shin Tsuge, Hajima Ohtani, Chuichi Watanabe
Hardcover ISBN: 9780444538925
eBook ISBN: 9780444538932

Chromatograms and mass spectra for isotactic PP
1. MALDI: SpiralTOF MALDI TOF/TOF System

1. Linear mode for high $m/z$
2. Spiral mode for high mass-resolving power
3. TOF/TOF for MS/MS with monoisotopic precursor selection

17-meter flight path in 1m distance
- Eliminates PSD artifacts
- Minimizes effect of delayed extraction on mass-dependent resolving power
- Minimizes effect of non-flat samples
- TOF/TOF ion gate at 15m point for monoisotopic precursor selection
Polystyrene MALDI spectra

Linear TOF mode:
PS average MW 100 kDa and 200 kDa

Spiral mode:
PS average MW 1000 and 10,000

TOF/TOF mode”
[M + Ag]+ at m/z 1,101.5462

Linear mode: Ag+ adducts for polystyrene

Average MW 100 kDa

Average MW 200 kDa

High-mass MW Distribution, low mass resolving power
Spiral mode: Ag+ adducts for polystyrene

High mass-resolving power (> 75,000). Accurate m/z measurements.
TOF/TOF mode: high-energy CID

PS (poly(styrene))

Structure, adduct and end group information.
Peak assignments

I don’t have the original data, so I scanned the mass spectrum from the graphic in the booklet by using the NIST Mass Spectrum Digitizer
2: GC-MS High-resolution Time-of Flight mass spectrometer: AccuTOF™ GC-Alpha

- Simple ion optics
- High mass resolving power (>30,000)
- High mass accuracy (sub-mmu)
- High speed (50 Hz) -- compatible with GCxGC
- Wide mass range (m/z 4 up to m/z 6400)
- All ion sources and direct sample introduction methods
- Field Ionization (FI) and Field Desorption (FD) options
- Combination ion sources (EI/FI and EI/PI)
- Easy ion source exchanges with very fast pump-down
- The most powerful data analysis software available
Sample introduction: Frontier Lab Multi-Shot Pyrolyzer (EGA/PY-3030D)

- Most samples were run in my lab in EGA mode with a blank GC column.
- Isotactic, atactic, syndiotactic PP were analyzed at JEOL Ltd. with pyrolysis GC-MS.
Ionization Methods for GC-MS

**Electron Ionization**
- Hard ionization
- Good for structural analysis using the generated fragment ions
- Able to change the ionization energy, typically use 70eV

**Chemical Ionization**
- Soft ionization
- Effective for compounds with higher proton affinities
- Negative-ion mode is available
- Reagent gas required

**Photo Ionization**
- Soft ionization
- Ionization energy is about 10.3eV (D2 lamp)
- Good for aromatic compounds
- No reagent gas required

**Field Ionization**
- Softest ionization
- Energies imparted to the molecules are less than 1eV
- Effective even for lower polarity molecules
- No reagent gas required
EI: A simple mass defect plot can be useful to spot outliers

Question: What are these peaks??
Pyrolysis EI MS of chloroprene: What is this tiny cloud of points?

- Artifact of the TOF: X
- Doubly charged ions: ✓
- Halogenated peaks: X
- Weird peaks: X
- I don't like GC-MS: X
Hint: the mass defect differs by 0.5 from the main peaks.
They are double charge peaks!

\[ \Delta m/z = 0.5 \]
Photoionization (PI)

- Ionizes compounds with ionization energies lower than the photon energy (10.8 eV)
- Simple to use: Just turn on the lamp -- can be used with combination EI/PI source
- More sensitive than FI for certain compound classes (e.g. PAH’s), but less sensitive for others (e.g. alkanes)
- Slightly more fragmentation than FI, but simpler spectra than CI
Pyrolysis GC-MS of polypropylene. Molecular ions for monounsaturated hydrocarbons in the pyrolysate

![Graph showing EI and PI modes of GC-MS analysis]

- **EI Mode:**
  - No molecular ion detected.
  
- **PI Mode:**
  - Molecular ion $\text{C}_{24}\text{H}_{46}^+$ detected.
  
**PI** gives more fragmentation than FI, but the molecular ion is still detected. PI fragmentation can provide structural information about branching, etc.
FI – An ideal ionization technique for molecular weight determination

- A soft ionization technique with minimal fragmentation, FI is ideal for samples that are volatile but easily fragmented with EI and CI
- Unlike CI, FI uses no reagent gas; no need to choose a reagent gas appropriate for the analyte

A sample vaporized by GC or the standard sample inlet is introduced to the vicinity of the emitter.

- FD: samples deposited directly onto emitter
- FI: samples introduced through GC
- LIFDI: liquid introduction field desorption ionization also available.
Polystyrene (PS)

- All show styrene
- FI shows $M^+$: For S1 to S4 (S3 most abundant)
LDPE
Low density polyethylene

- PI shows $M^+$ and fragments
- FI shows high-$m/z$ $M^+$
Data analysis approaches for pyrolysis data

- We cannot get MW distributions from the pyrolysis data.
- Kendrick mass defect (KMD) analysis very useful with PI and FI data
- Resolution-enhanced KMD simplifies interpretation
  - Deisotoping with divisor 21 to separate even and odd masses
- C vs. DBE plots and/or bar chart summary for abundance vs. unsaturation
- van Krevelen plots for oxidized polymers, polymers with heteroatoms
- High-resolution accurate-mass data useful for chlorinated and oxidized polymers.
Resolution-enhanced Kendrick mass defect plots (REKMD)

Kendrick mass defect analysis

Data points have been peak-picked from the mass spectra using an automated procedure implemented in mMash with no deisotoping and a relative intensity threshold set at 5%. The accurate mass measurements of ions on the IUPAC scale were converted to KMs, NKMs and KMDs according to:

\[
KM(\text{ion}) = m/z(\text{ion}) - \text{round}(m(\text{base unit}))
\]

(1)

\[
NKM(\text{ion}) = \text{round}(KM(\text{ion}))
\]

(2)

\[
KMD(\text{ion}) = NKM(\text{ion}) - KM(\text{ion})
\]

(3)

Contrary to the previous reports,\(^{20-22,26}\) the base unit in the present article is a fraction of the repeat unit noted (repeat unit)/X with the divisor X being an integer ranging from 1 to 10 (10 has been arbitrarily chosen for the sake of simplicity). While the value of X is increasing, the value of NKM is departing from the actual m/z value. To prevent any shift of the plots, a “corrected” NKM value was calculated according to:

\[
NKM_{\text{corrected}}(\text{ion}) = NKM(\text{ion}) - \text{ceiling}(NKM(\text{ion}) - m/z(\text{ion}))
\]

(4)

Deisotoping hydrocarbon mass spectra: LDPE/F1

- Create a fractional KMD plot
  - Base unit CH$_2$
  - Divisor 21
- $^{13}$C Isotope peaks will separate from $^{12}$C isotope peaks
  - Use with caution if N is present!

$^{12}$C monoisotopic peaks
Fractional KMD Plot for FI of deisotoped LDPE
Base unit: CH₂, divisor 13
Oxidized PE: Pyrolysis (EGA) Photionization

Oxidation is not obvious at first glance.

LDPE

HDPE

Oxidized PE
High MS resolution is required to see oxidation without GC separation.
First, let’s deisotope the oxidized PE and remove odd-m/z fragments

Fractional KMD plot,
Base unit = CH2
Divisor = 21
REKMD plot for oxidized PE shows oxidized peaks
van Krevelen plot for oxidized PE


Does anyone have this article???
Polypropylene (PP)

atactic (aPP)
- amorphous
  - $T_g = -10 \, ^\circ C$
  - $T_m = -$

syndiotactic (sPP)
- semicrystalline
  - $T_g = -8 \, ^\circ C$
  - $T_m = 160 \, ^\circ C$

isotactic (iPP)
- semicrystalline
  - $T_g = 0 \, ^\circ C$
  - $T_m = 184 \, ^\circ C$

Isotactic
Syndiotactic
Atactic
PP (isotactic)

- PI and FI show C3 differences
- FI is best
C₃H₆ mass differences in FI mass spectrum of isotactic PP
Fractional KMD Plot for Fl of isotactic PP
Base unit: CH₂, divisor 13

- Saturated
- One double bond
- Two double bonds
- Three double bonds
Fractional KMD Plot for FI of isotactic PP
Base unit: \( \text{C}_3\text{H}_6 \), divisor 43

Three series. Each differs by a \( \text{CH}_2 \)
Pyrolysis of PVC

- HCl released early
- PAH’s
- PI gives clearest data
Different ways to view the PVC data

Double bond equivalents vs. carbon number

Naphthalene
Benzene

Double bond equivalents vs. rel.

Relative abundances for C:\Exported_Data\Polymer synthesis\PVC_P1.txt

REKMD
Application data: Pyrolysis of polypropylene

Gas Chromatograph-Time-of-Flight Mass Spectrometer
JMS-T2000GC Sample Measurement Result

May 31, 2023

JEOL Ltd.
MS marketing group
Takao Fukudome
tfukudom@jeol.co.jp

MS application 2 group
Measurement conditions: Py-GC-MS

- Sample
  A: Polypropylene (Isotactic), B: Polypropylene (Amorphous)

- Py condition
  - Mode: Single shot
  - Furnace temperature: 600°C

- GC condition
  - Injection mode: Split 50:1
  - Column: HP-5 MS UI, 30 m length, 0.25 mm i.d., 0.25 mm film thickness
  - Inlet temperature: 300°C
  - Oven condition: 40 (2 min hold) - 10°C/min - 320 (60 min hold)
  - Carrier gas: He, 1.5 mL/min

- TOFMS condition
  - Ionization: El: Ionization energy 70 eV
                  Fl: Cathode voltage -10 kV, Emitter current 40 mA, Baking time 30 msec
  - Mass range: m/z 35-800
TIC chromatograms for EI

msFineAnalysis AI aligns and correlates the EI and FI data, followed by statistical analysis of the two samples.

TICC were similar, but the peak intensities were different.
Variance component analysis was performed on 75 peaks with an intensity ratio over 2%.
msFineAnalysis-volcano plot and peak list

The detected peaks from two samples were common, but their intensities were different.

Sample A (Isotactic)

Sample B (Amorphous)

Peaks were strong in sample B (Amorphous)
→ Low boiling point and low mass

Peaks were strong in sample A (Isotactic)
→ High boiling point and high mass
The three peaks of C15 had differences in intensity between samples.

ID022: Strong in sample A (Isotactic)
ID023: Strong in sample B (Amorphous)
ID024: Same in sample A and B
The relative intensities were similar to our measurement results.
This compound is registered in the NIST library. But the mass spectrum is slightly different. So no hits in the library search.

The data may be outdated and the structure may be incorrect.
AI structure analysis was able to derive a structure which suggested thermal decomposition products of polypropylene.
The same structure as ID022 was derived with similar score.
msFineAnalysis-Detail of ID024

The same structure as ID022 and 023 was derived with similar score.
Use of user library

AI structural analysis does not distinguish between stereoisomers. It becomes possible to distinguish by using a NIST user library (=private library).
Use of user library

Library search with user library can distinguish stereoisomers by similarity and RI.
3. Thermal desorption/pyrolysis DART

JEOL AccuTOF-DART 4G mass spectrometer

- Protocol is analogous to evolved gas analysis
- Temperature control from ambient to 600°C

Biochromato ionRocket thermal desorption and pyrolysis accessory


Samples (typically ~ 1 mm diameter) placed into copper “pot”

The sample pot and heater block (1) slide into position below a glass tee (2) mounted between the DART exit (3) and the mass spectrometer sampling orifice (4).

The copper sample pot (1) is placed onto the heater block (2) on a sliding stage.
LDPE with ionRocket

Oxygen plays a key role in the DART pyrolysis
Polybutadiene by direct DART differs from same polymer with ionRocket

Butadiene oligomers are indistinct

Butadiene oligomers are very clear

$[(C_4H_6)_n + H]^+$ is the dominant species
The butadiene oligomers are not clearly evident with EI, PI, FI
Another case where TD/Py DART shows complementary data

TD/Py DART of chlorinated isoprene (65% Cl) shows $C_8H_7Cl$ (chlorostyrene?) and oxidized peaks with related compositions.

Pyrolysis EGA of chlorinated isoprene (65% Cl) shows only HCl in El mode. No ions are detected by PI or FI.
ABS: Mostly HC polymer with some heteroatoms

EI, CI, PI, FI, DART

Acrylonitrile

1,3-Butadiene

Styrene

DART
**ABS:** HC polymer with some heteroatoms

**PI:** molecular ions and fragments

**FI:** molecular ions, easily interpreted

**DART:** most information, harder to interpret, oxidation

Overview: no single method is ideal for all applications.

<table>
<thead>
<tr>
<th>Method</th>
<th>Pros</th>
<th>Cons</th>
</tr>
</thead>
<tbody>
<tr>
<td>EI</td>
<td>GC-MS and database search can be used with quadrupole MS. Can ID fragments, additives, contaminants. mSfineAnalysis AI can integrate EI data with soft ionization data.</td>
<td>Limited information without GC</td>
</tr>
<tr>
<td>CI</td>
<td>Better for polymers with heteroatoms. More sensitive than PI and FI, but more complex spectra than either.</td>
<td>Not much more information than EI for HC polymers</td>
</tr>
<tr>
<td>PI</td>
<td>Molecular ions, fragments. More sensitive than FI for aromatics. Best information for oxidized hydrocarbon polymers.</td>
<td>More fragmentation than FI</td>
</tr>
<tr>
<td>FI</td>
<td>Excellent MW information, little or no fragmentation. Can ID polymers without GC.</td>
<td>Poor or useless for heavily chlorinated polymers</td>
</tr>
<tr>
<td>DART</td>
<td>Fast, easy, sample overload not an issue. Direct analysis or indirect analysis with TDP/DART. Sometimes more information than other methods (e.g. polybutadiene)</td>
<td>Can't detect oxidized PE because O2 plays a role in ionization. No quantitation. Direct DART may differ from indirect TDP/Py DART.</td>
</tr>
<tr>
<td>MALDI</td>
<td>MW distribution, TOF/TOF data</td>
<td>Limited applications to HC polymers</td>
</tr>
</tbody>
</table>
Summary:

- PS can be analyzed by MALDI, other HC polymers require derivatization or pyrolysis methods.
- Pyrolysis GC-MS is a well-established method with commercially available automation, hardware and software. Compatible with low-cost GC-MS platforms as well as GC-HRMS systems.
- EI is most useful with GC separation and database search.
- CI is not especially helpful for polymers that only contain C and H.
- Pyrolysis PI and FI give excellent MW data for pyrolysis fragments, but do not detect evolved HCl from chlorinated HC polymers.
- TD/Py DART gives distinctive spectra for polymers, resembles pyrolysis CI data.
- Direct DART desorption spectra may differ from indirect (ionRocket) data. (Polybutadiene, natural rubber examples)
- KMD analysis useful for all HC polymers.
Which program(s) do you know?

- Polymerix
- kendo
- Investigator
- SpectraScope
- MSRepeatFinder
- Mass Mountaineer
- Orion
- MZMine 2
- Others
Demo (time permitted)

- Live processing of a few data files from hydrocarbon polymers
  
  Thierry Fouquet, Bausch and Lomb
Reactions were monitored in situ by $^1$H NMR spectroscopy.

1,3,5-trimethoxybenzene internal standard was used to quantify consumption of alkene by comparing integration of $\alpha$-resonance of pendant vinyl group before and after 24 h of heating.

Amine patterning along polymer chain unknown, assumed random and homogenous.

Materials were purified by filtration through Celite™, precipitation into cold MeOH from DCM, then dried in vacuo.

Characterization by multi-nuclear NMR spectroscopy of isolated materials suggest little-to-no chain decomposition and no undesired by-products.

Isolated materials are clear and range between colourless and dark brown depending on amine and degree of amination.
MALDI data with DCTB matrix, silver trifluoroacetate salt.

Linear mode

Reflector mode
MALDI-ToF MS data (close up)

Exact Mass: 2759.24

Exact Mass: 2813.28

Linear

Reflector
MALDI-ToF MS data (close up)

Exact Mass: 1786.39
MALDI-ToF MS data of the low aminated material

Calculated from intensity of each signal in MALDI-ToF spectrum:

\[ M_n = 2868 \text{ g/mol} \]
\[ M_w = 2938 \text{ g/mol} \]
\[ PDI = 1.02 \]

Estimated \( M_n \) after amine functionalization: 2828.29 g/mol

Questions:
- How confident can we be about molecular weight and PDI calculations?
- There are clusters of peaks surrounding most abundant peak, could this be fragments or dispersity due to differing degrees of functionalization?
- Is there any way to extract information about polymer microstructure from this (ie knowing where the amine is on the chain)
MALDI-TOF MS data: expansion of the aminated materials

Clusters of peaks $\Delta = +5$ from each other. The polymer n-3 plus an amine function is $+5$.

Average Mass = 2934.72

Average Mass = 2939.74
MALDI-ToF MS data of the low aminated material
MALDI-ToF MS data of the low aminated material
MALDI-ToF MS data of the low aminated material

Avg Mass (33,11,2): 2880.63
  2881.173

Avg Mass (35,12,1): 2875.61
  2876.894

Avg Mass (31,10,3): 2885.65
  2886.189

Avg Mass (29,9,4): 2890.67
  2892.234

Avg Mass (27,8,5): 2895.69
  2898.251

Avg Mass (25,7,6): 2900.71
  2902.161

m/z
MALDI-ToF MS data of the low aminated material

We do know that these are between 1 and 6 aminations.

Are there other MS systems (e.g. IMS-MS) that can tell us the distribution of the amines (e.g. are the amines (and the 1,2-double bonds) more on one end, or are these a random distribution)?

Can we do higher aminations (we only had 5% of aminations)?

Any addition things that we can answer?
Innovations in Materials Characterization Technology Summit | August 7-9 at CMU

- Conference-style interactions and presentations with delegates from academia, government, and industry

- Topics to be discussed:
  - Chromatography
  - Mass Spectrometry
  - Thermal Analysis
  - Rheology
  - Nuclear Magnetic Resonance Spectroscopy
  - Modeling
  - Synthesis
  - Sustainability
Summit Activities

- Tour of CMU Cloud Lab, remotely operated laboratory featuring over 200 instrument types supporting research in chemistry, biology, and material sciences

- Research Posters

- Confirmed Speakers
  - Krzysztof Matyjaszewski, Carnegie Mellon University
  - Amit Ghosh & Mark Morris, Covestro
  - Tara Meyer, University of Pittsburgh
  - Tony Giles, Dow
  - Mark Bier, Carnegie Mellon University
  - Brett Fors, Cornell University
  - Kathryn Beers, NIST
  - Daphne Chan, Carnegie Mellon University
  - Catherine Smith, Arkema
  - Rachel Behrens, University of California—Santa Barbara
  - Chrys Wesdemiotis, The University of Akron
  - Miroslav Janco, Dow
  - Thierry Fouquet & Drew Hoteling, Bausch & Lomb
  - Chris Shaffer & Aaron Hedegaard, 3M
  - And more...

For more information contact: Bryan Katzenmeyer at bryan_katzenmeyer@waters.com
JEOL is hiring!

Business Development Manager - Polymers & Industrial Markets

Search for JEOL on the ASMS Career Page


Or

https://bit.ly/3IYrX7B
Next year's topic? 2 Answers

Deformation

Nice job with the seminar at the workshop!!!