Development of isotope microscope and in-situ observation of presolar grains and other anomalous materials

Hisayoshi Yurimoto
Hokkaido Univ.
Outline

• Paradox between chemical and isotope petrography of CAIs
• Point to Line SIMS analysis
• Development of isotope microscope
• Advancement of Isotopography
• Astrophysical dynamic setting for CAI formation
• Surprises
  – Presolar grains
  – Cosmic symplectite (COS)
• Development of isotope nanoscope
Petrography of Coarse-grained CAIs

- Crystallized from a liquid droplet
  - Mineral assemblage
  - Chemical petrography of minerals
Coarse-grained CAIs

Crystallization sequence

Isotope distribution

after Wood and Hashimoto (1993) and Stolper (1982)

after Clayton (1993)
Outline

• Paradox between chemical and isotope petrography of CAIs
• Point to Line SIMS analysis
• Development of isotope microscope
• Advancement of Isotopography
• Astrophysical dynamic setting for CAI formation
• Surprises
  – Presolar grains
  – Cosmic symplectite (COS)
• Development of isotope nanoscope
Point to Line analysis 1

Point to Line analysis 1

Point to Line analysis 1

Point to Line analysis 1

Point to Line analysis 1

Point to Line analysis 1

Diffusion profile: limited to ~10 µm
Cooling rate: 50-200 °C/hour from 1600 °C

Point to Line analysis 1

Point to Line analysis 2

7R-19-1 in Allende (Science, 1998)
Point to Line analysis 2

7R-19-1 in Allende (Science, 1998)
Point to Line analysis 2

7R-19-1 in Allende (Science, 1998)
Point to Line analysis 2

7R-19-1 in Allende (Science, 1998)
Point to Line analysis 2

Mel1 ➞ Sp Fas1 ➞ Fas2

7R-19-1 in Allende (Science, 1998)
7R-19-1 in Allende (Science, 1998)
Point to Line analysis 2

7R-19-1 in Allende (Science, 1998)
Point to Line analysis 2

\[ \text{Sp} \xrightarrow{\text{Mel1}} \text{Fas1} \]
\[ \text{Fas3} \xrightarrow{\text{Mel2}} \text{Fas2} \]

7R-19-1 in Allende (Science, 1998)
Point to Line analysis 2

7R-19-1 in Allende (Science, 1998)
Point to Line analysis 2

[Diagram showing Akermanite content and δ¹⁷O values along a line with cracks and distance markers.]

Mel1 ↔ Sp Fas1
Fas3 ↔ Fas2 Mel2
Point to Line analysis 2

7R-19-1 in Allende (Science, 1998)
Development of Isotope Microscope
Outline

• Paradox between chemical and isotope petrography of CAIs
• Point to Line SIMS analysis
• **Development of isotope microscope**
• Advancement of Isotopography
• Astrophysical dynamic setting for CAI formation
• Surprises
  – Presolar grains
  – Cosmic symplectite (COS)
• Development of isotope nanoscope
Development of Isotope Microscope
SCAPS

600 x 600 pixels
20 µm²/pixel

Pixel structure

V-Scanner
H-Scanner
Output
Development of Isotope Microscope

This refractory incl. is homogeneously enriched in $^{16}$O ($\Delta = \sim 50\%$).
Development of Isotope Microscope

Si of SiO₂/Si test pattern

300 nm width
Outline

• Paradox between chemical and isotope petrography of CAIs
• Point to Line SIMS analysis
• Development of isotope microscope
• Advancement of Isotopography
• Astrophysical dynamic setting for CAI formation
• Surprises
  – Presolar grains
  – Cosmic symplectite (COS)
• Development of isotope nanoscope
Isotopography of oxygen

TTV1-01 in Vigarano (GCA, 2005)

Continuous O isotopic distribution
Isotopography of oxygen

TTV1-01 in Vigarano (GCA, 2005)

Continuous O isotopic distribution
Isotopography of oxygen
Isotopography of oxygen

Bimodal O isotopic distribution
Isotopography of oxygen

Bimodal O isotopic distribution
Isotopography of oxygen

CAI in Acfer 094
This CAI was directly condensed from gas.

Nebular gas changed $^{16}$O-rich to $^{16}$O-poor.
Outline

• Paradox between chemical and isotope petrography of CAIs
• Point to Line SIMS analysis
• Development of isotope microscope
• Advancement of Isotopography
• Astrophysical dynamic setting for CAI formation
• Surprises
  – Presolar grains
  – Cosmic symplectite (COS)
• Development of isotope nanoscope
Astrophysical setting of CAI formation
Outline

• Paradox between chemical and isotope petrography of CAIs
• Point to Line SIMS analysis
• Development of isotope microscope
• Advancement of Isotopography
• Astrophysical dynamic setting for CAI formation
• Surprises
  – Presolar grains
  – Cosmic symplectite (COS)
• Development of isotope nanoscope
Surprises: in situ observation of presolar grains

Surprises: in situ observation of presolar grains

Presolar silicate grain

Presolar carbonaceous grains
Surprises: Cosmic symplectite (COS)

in Acfer 094, Science (2007)
Surprises: Cosmic symplectite (COS)

in Acfer 094, Science (2007)
Outline

• Paradox between chemical and isotope petrography of CAIs
• Point to Line SIMS analysis
• Development of isotope microscope
• Advancement of Isotopography
• Astrophysical dynamic setting for CAI formation
• Surprises
  – Presolar grains
  – Cosmic symplectite (COS)
• Development of isotope nanoscope
Development of Isotope nanoscope

Ga FIB for nano probe

for post ionization
fs Laser

MULTUM ToF for high mass resolution

SCAPS detector for simultaneous measurement
Development of Isotope nanoscope

Target: Ag

Non-resonant ionization

Power: 2.50 W

SIMS
Development of Isotope nanoscope

Linear (0.8 m)
Mass resolving power: 500

10 cycles (13.8 m)
Mass resolving power: 7500
Isotopic Petrography: State and Prospects

- Isotopic petrography reaches real micrometer scale.
- Nano-scale is a treasury of pre-solar history information.
- Isotopic petrography on real nano-scale should be advanced.