The NASA MSFC Electrostatic Levitation (ESL) Laboratory –
Summary of Capabilities, Recent Upgrades, and Future Work

Michael P. SanSoucie
David J. Vermilion
Jan R. Rogers
NASA Marshall Space Flight Center (MSFC), Huntsville, AL

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Outline

- Laboratory Capabilities
- Rapid Quench System
- Oxygen Partial Pressure Control
- High Temperature Emissivity Measurement System (HiTEMS)
MSFC Electrostatic Levitation (ESL) Laboratory

- Michael SanSoucie (EM50)
- Jan Rogers (EM50)
- Paul Craven (EM50)
- David Vermilion (EM50)
- Trudy Allen (METTS)
- Glenn Fountain (ESSSA)
- Curtis Bahr (ESSSA)
The MSFC ESL Lab is a national resource for researchers developing advanced materials for new technologies.

**Electrostatic levitation**
- Containerless process
  - Eliminates any container-sample interaction
  - Allows for deep undercooling of samples
- Can process elements, alloys, refractory metals, superalloys, ceramics, oxides, and glasses
- The lab typically measures thermophysical properties
  - Density
  - Surface tension
  - Viscosity
  - Phase diagram studies
- The lab hosts government, academic, and commercial investigators
- Provides ground-based support for US investigators with levitation experiments on ISS
  - ESA’s Materials Science Laboratory Electromagnetic Levitator (MSL-EML)
  - JAXA’s Electrostatic Levitation Furnace (ELF)
- The lab has two levitators
- The lab’s main levitation chamber has a broad range of capabilities
  - Creep measurement
  - Triggered nucleation
  - Solidification velocity measurement
  - Oxygen partial pressure control
  - Ability to run in a gaseous environment up to 5 atm
  - Rapid quench
Portable chamber

- Brought to Argonne National Laboratory
- Used in a high-energy beamline for determination of equilibrium and non-equilibrium phase diagrams\(^1\)
- Used for structure and phase determination of quasicrystals\(^2\)

Now used for

- phase diagram studies
- density
- surface tension
- viscosity
- test plan development
- processing of volatile or challenging materials

References:


More details about the ESL lab can be seen at: https://partnerships.msfc.nasa.gov/content/electrostatic-levitation-laboratory
Rapid Quench System

- Rapid quench system
  - Samples are dropped into a quench vessel filled with a low melting point material
    - Thereby allowing rapid quenching of undercooled liquid metals
    - Typically use a gallium-indium alloy (61Ga 25In 13Sn 1Zn) as a quench medium

- Stepper motors controlled by LabVIEW are used to turn the quench wheel as well as to raise and lower the stem

- Quench vessels can be raised or lowered using the same stem that is used to launch the samples

- Up to 8 quench vessels can be loaded into the quench wheel

- An exploded view of the system is shown to the left
Rapid Quench System

Quench wheel, stem, and quench vessel

Quench vessel filled with a gallium-indium alloy
Quench Sequence
Quench Video

• Show video of sequence from previous slide
Quench Video

• Video showing recalescence
Oxygen Partial Pressure Control

- Developed by Astrium North America
- Fabricated by Clausthal University of Technology (TU Clausthal)
Necessity for Oxygen Partial Pressure Control

- Supports microgravity investigations
  - An oxygen partial pressure control system is planned for the European Space Agency (ESA) Materials Science Laboratory Electromagnetic Levitator (MSL – EML) on the International Space Station (ISS)

- Surface tension of molten metals is affected by even a small amount of adsorption of oxygen
  - Oxidation may have an impact of 10-30% on surface tension measurements²

- The ESL lab has performed studies on the effects of oxygen partial pressure on the thermophysical properties of liquid nickel³

References:
Oxygen Sensing and Pumping

- Potentiometric sensor
  - Determines the difference in oxygen activity in 2 gas compartments separated by an electrolyte
    - Yttria-stabilized zirconia (YSZ)
  - The cell generates an electromotive force
    - \( p_{O_2} \) is calculated by using the Nernst equation
      \[
      E = \frac{RT}{4F} \ln \left( \frac{p_{O_2}}{p_{O_2}^{ref}} \right)
      \]

- Pumping
  - Oxygen molecules move through the YSZ tube when a difference in electrical potential is provided between the tube walls
  - Electric current is applied to the electrodes (Pt)
    - Charge is moved across the electrolyte in the form of oxygen ions, \( O^{2-} \)
  - Negative electrode
    - Oxygen is incorporated into vacancies of the electrolyte, \( V_{O}^{00} \)
  - Positive electrode
    - Oxygen leaves the crystal lattice to form gaseous oxygen

Reference:

Reference:
Example of $p_{O_2}$ vs. time

Oxygen partial pressure vs time

Oxygen partial pressure during sample processing
The ESL laboratory also has an emissometer, called the High-Temperature Emissivity Measurement System (HiTEMS).

This system measures the spectral emittance and calculates total emissivity of materials from 600°C to 3,000°C.

The system consists of:
- vacuum chamber
- black body source
- Fourier Transform Infrared Spectrometer (FTIR)

Emissivity:
- A ratio of the radiant energy emitted per unit area from a real surface to the energy emitted from a black body at the same temperature
- Not a specific property of a material
  - Varies with texture and surface treatment

Black Body:
- A black body absorbs all incident electromagnetic radiation
- Perfect absorber is also a perfect emitter
- A body that absorbs the entire radiance incident upon it – not reflecting any or transmitting any – is called a black body
High Temperature Emissivity Measurement System (HiTEMS)

- HiTEMS utilizes optics to swap the signal to the FTIR between the sample and the black body

- The system was originally designed to measure the hemispherical spectral emittance of levitated samples
  - Levitation allows emittance measurements of molten samples; however, more work is required to develop this capability

- It is currently setup to measure the near-normal spectral emittance of stationary samples
  - Approx. 3/8” x 3/8”, thin samples

- Examples of materials tested in HiTEMS
  - ablative materials
  - composite materials (RCC leading edge)
  - rocket nozzle coating materials (J2X nozzle extension)
  - materials for spacecraft instruments
Conclusions

• The NASA Marshall Space Flight Center (MSFC) electrostatic levitation (ESL) laboratory has recently added two new capabilities
  – Rapid quench system
  – Oxygen partial pressure control system

• The rapid quench system allows for studies of solidification of a variety of materials
  – Studies of double recalescence are planned
  – The quench of a sample during second recalescence will be attempted in order to retain the primary metastable structure

• Oxygen partial pressure can have a large impact on the thermophysical properties of materials

• High-Temperature Emissivity Measurement System (HiTEMS)
  – Measures the spectral emittance and calculates the total emissivity of materials from 600°C to 3,000°C
  – Emissivity is an important property for thermal modeling
  – Additional work on HiTEMS is ongoing