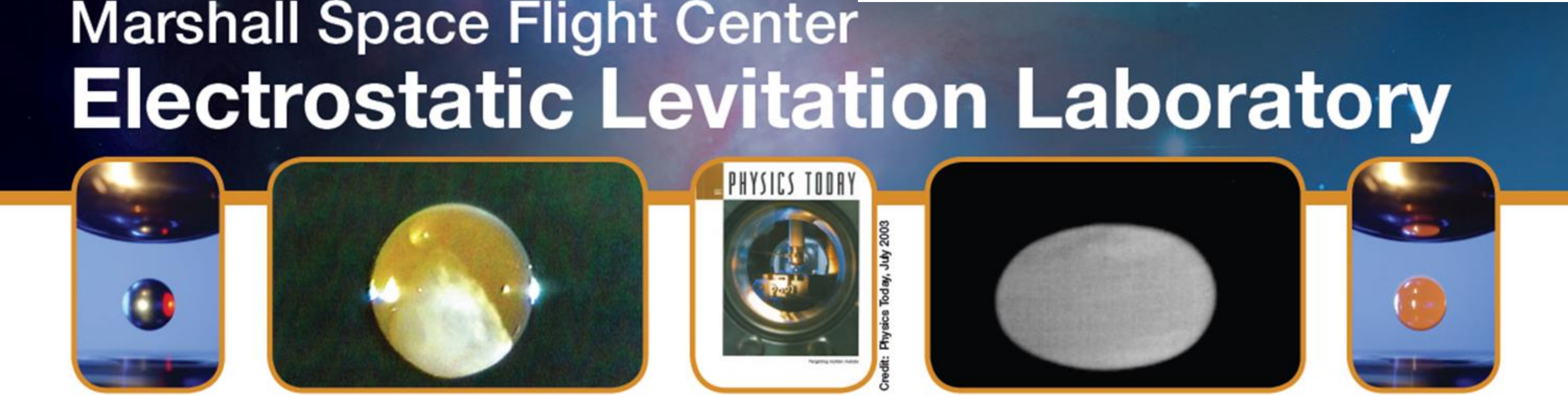

The NASA MSFC Electrostatic Levitation (ESL) Laboratory – Summary of Capabilities, Recent Upgrades, and Future Work

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for Gravitational and Space Research
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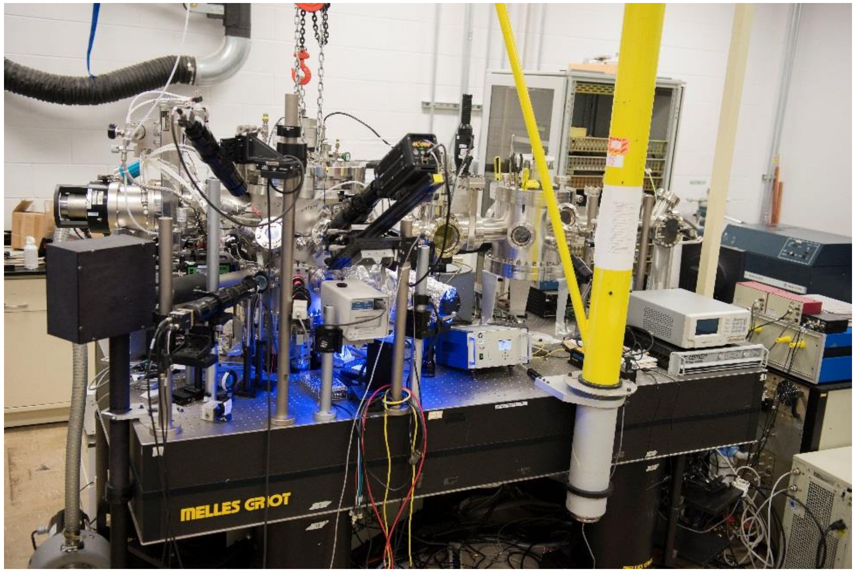
Outline

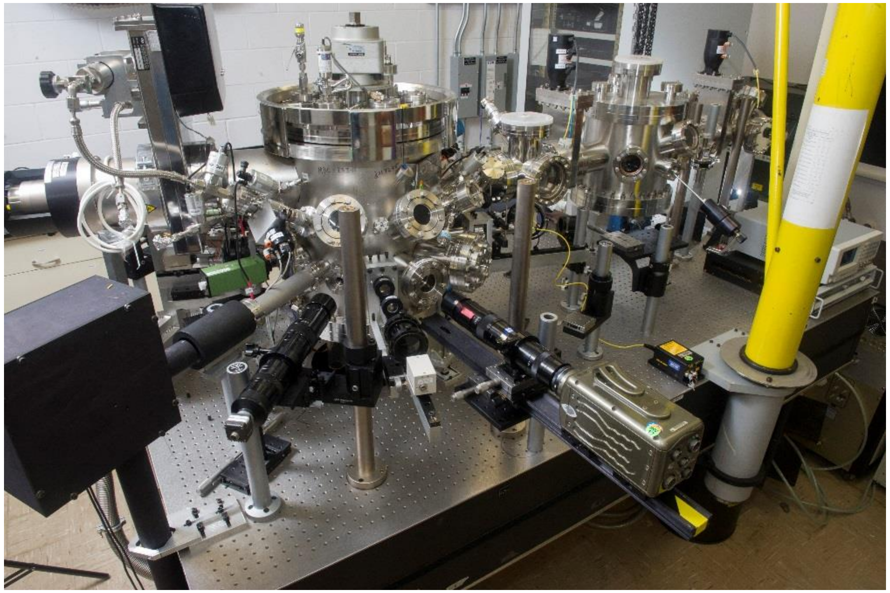
- Laboratory Capabilities
- Rapid Quench System
- Oxygen Partial Pressure Control
- High Temperature Emissivity Measurement System (HiTEMS)

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)

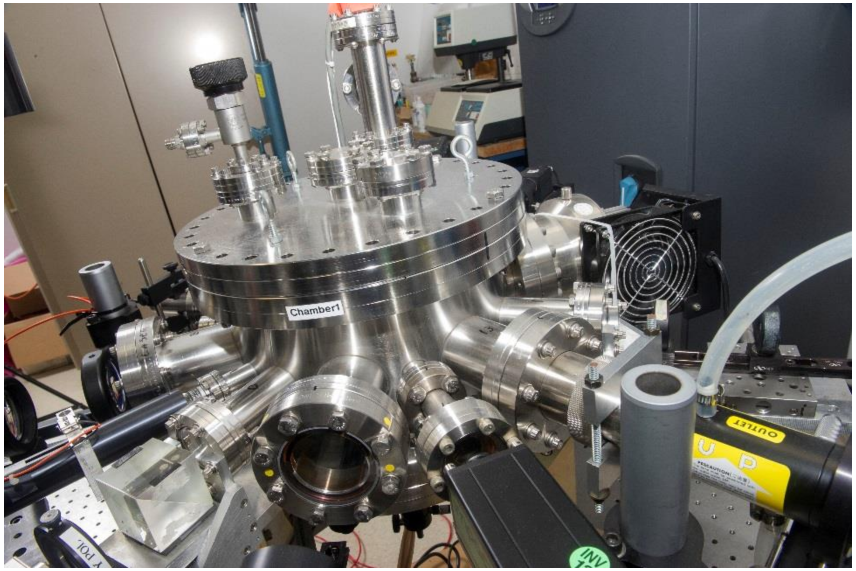
MSFC Electrostatic Levitation (ESL) Laboratory Main Chamber



Main chamber

- 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 undercooled 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 5atm
  - Rapid quench

MSFC Electrostatic Levitation (ESL) Laboratory Portable Chamber



Portable chamber

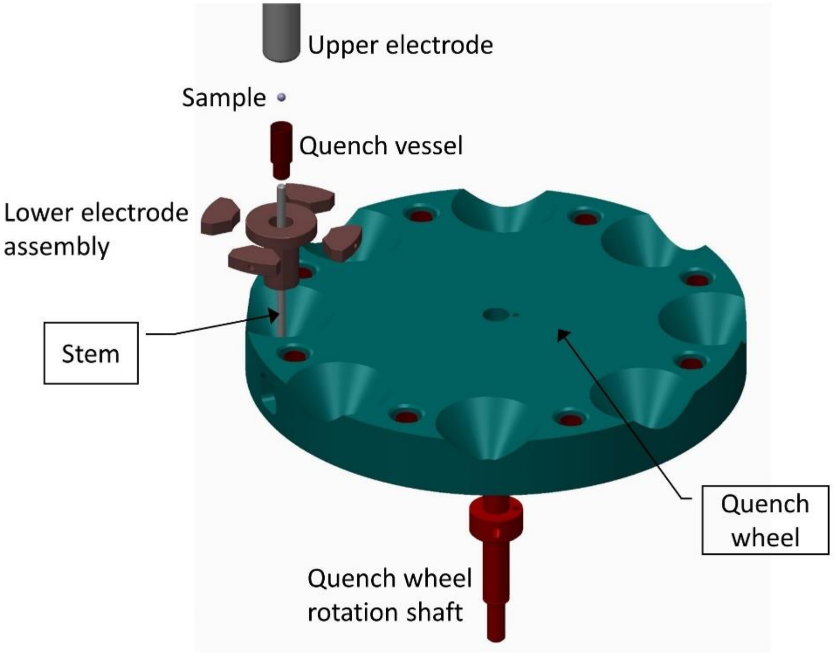
- Portable chamber
  - Brought to Argonne National Laboratory
  - Used in a high-energy beamline for determination of equilibrium and non-equilibrium phase diagrams[1]
  - Used for structure and phase determination of quasicrystals[2]
- Now used for
  - phase diagram studies
  - density
  - surface tension
  - viscosity
  - test plan development
  - processing of volatile or challenging materials

References:

1. Gangopadhyay, A.K., et. al., *Beamline electrostatic levitator for in situ high energy x-ray diffraction studies of levitated solids and liquids*, Review of Scientific Instruments 76, 073901, 2005
2. Kelton, K.F., et. al., *First X-Ray Scattering Studies on Electrostatically Levitated Metallic Liquids: Demonstrated Influence of Local Icosahedral Order on the Nucleation Barrier*, Physical Review Letters, 90, 195504, 2003

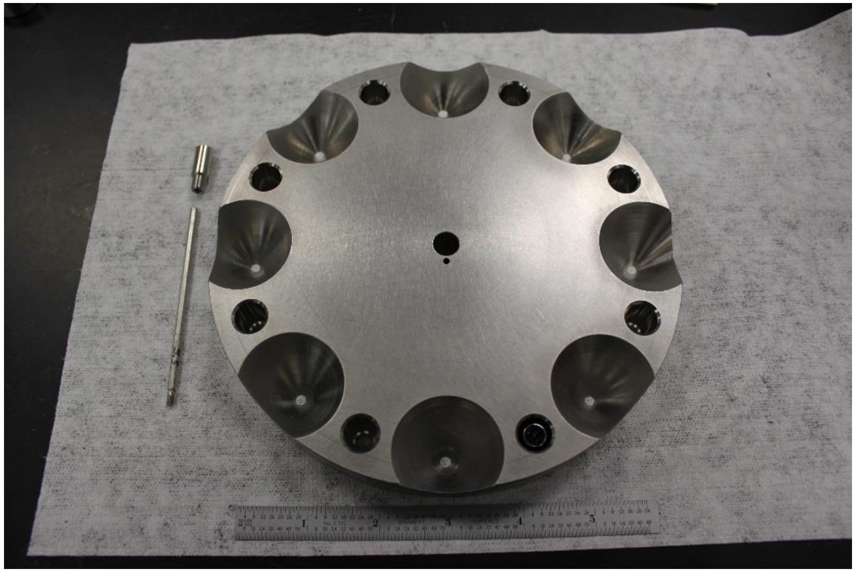
More details about the ESL lab can be seen at: https://partnerships.msfc.nasa.gov/content/electrostatic-levitation-laboratory

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

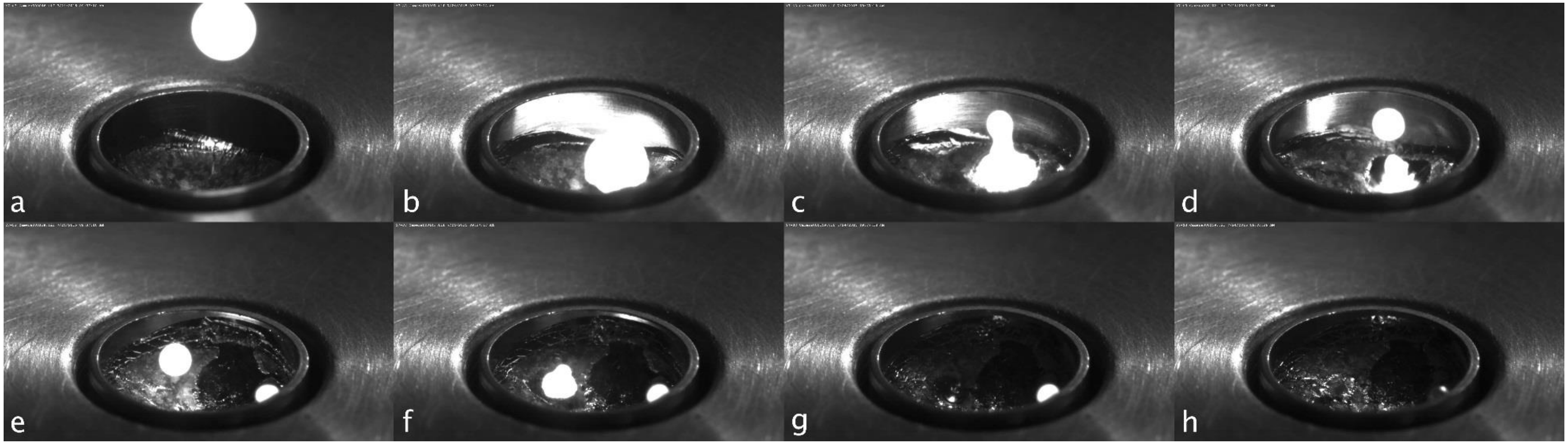
Rapid Quench System



Quench wheel, stem, and quench vessel

Quench vessel filled with
a gallium-indium alloy

Quench Sequence



Quench Video

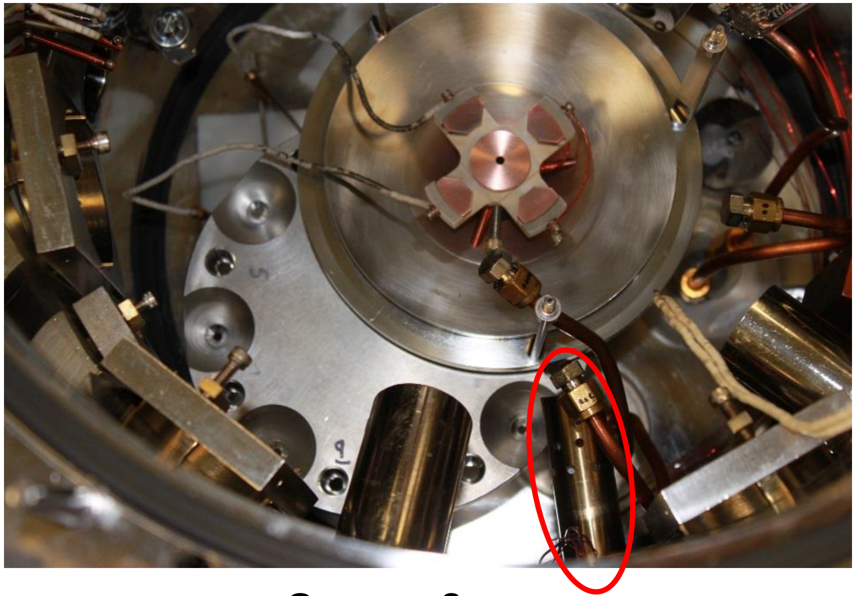
- Show video of sequence from previous slide

Quench Video

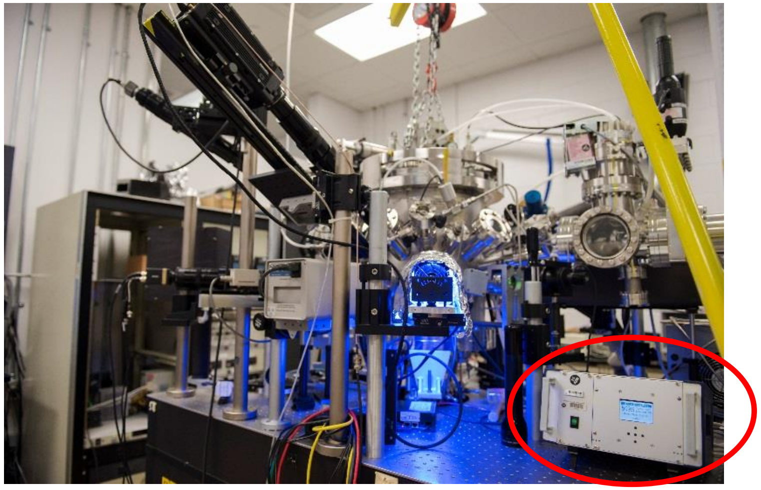
- Video showing recalescence

Oxygen Partial Pressure Control

Oxygen Pump



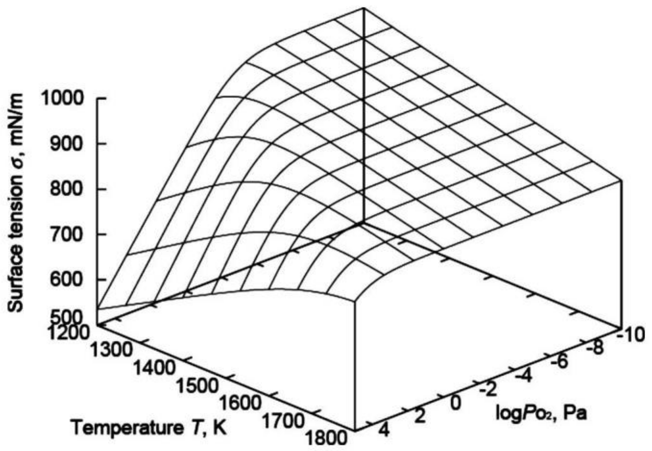
Oxygen Sensor



Controller

- Developed by Astrium North America
- Fabricated by Clausthal University of Technology (TU Clausthal)

Necessity for Oxygen Partial Pressure Control

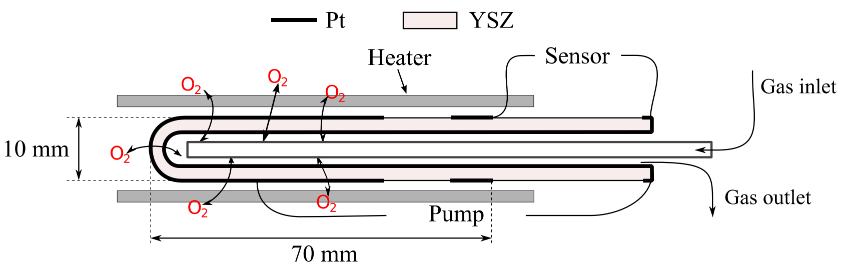


Measured relationship between surface tension, temperature, and p_{O_2} for molten silver[1]

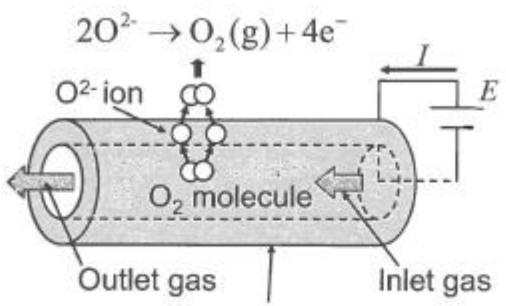
- Supports microgravity investigations
  - An oxygen partial pressure control system is planned for the European Space Agency (ESA) Materials Science Laboratory Electromagnetic Levitator (MSL – EML) on the International Space Station (ISS)
- Surface tension of molten metals is affected by even a small amount of adsorption of oxygen
  - Oxidation may have an impact of 10-30% on surface tension measurements[2].
- The ESL lab has performed studies on the effects of oxygen partial pressure on the thermophysical properties of liquid nickel[3]

References:
1. Ozawa, S., et.al., *Influence of oxygen partial pressure on surface tension of molten silver*, Journal of Applied Sciences, 2010, 107, p. 014910
2. DebRoy, T. and S.A. David, *Physical processes in fusion welding*, Reviews of Modern Physics, 1995, 67(1), p. 85-112
3. SanSoucie, M., et. al., *Effects of Oxygen Partial Pressure on the Surface Tension of Liquid Nickel*, 19th Symposium on Thermophysical Properties, Boulder, CO, June 21-26, 2015

Oxygen Sensing and Pumping



Reference: Schulz, M., et al., *Oxygen partial pressure control for microgravity experiments,* Solid State Ionics, 2012, 225, p. 332-336.



Schematic of oxygen ion pump

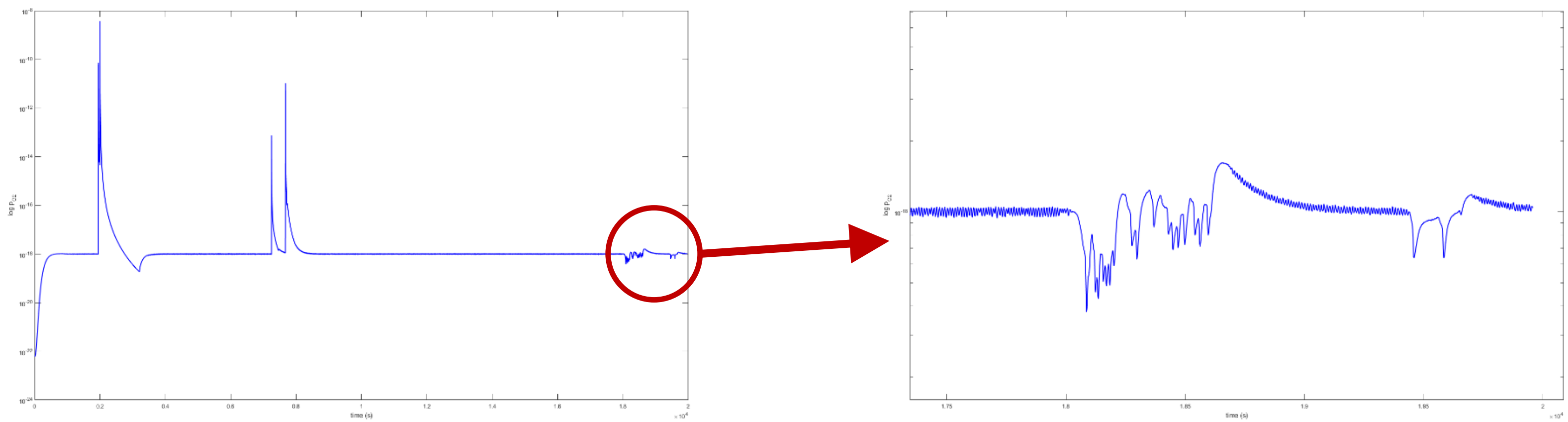
Reference: Ozawa, S., et al., *Influence of oxygen partial pressure on surface tension of molten silver,* Journal of Applied Physics, 2010, 107.

- 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

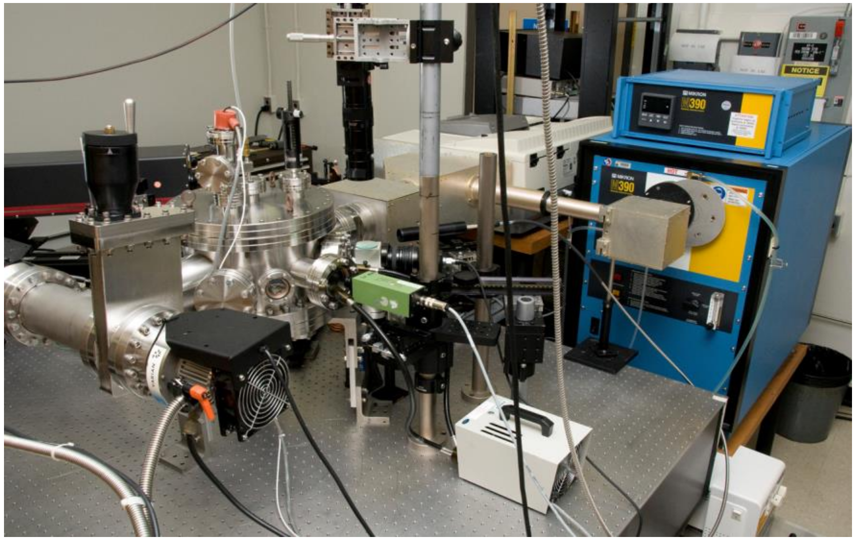
Example of p_{O_2} vs. time

Oxygen partial pressure vs time

Oxygen partial pressure during sample processing



High Temperature Emissivity Measurement System (HiTEMS)



- The ESL laboratory also has an emissometer, called the High-Temperature Emissivity Measurement System (HiTEMS)

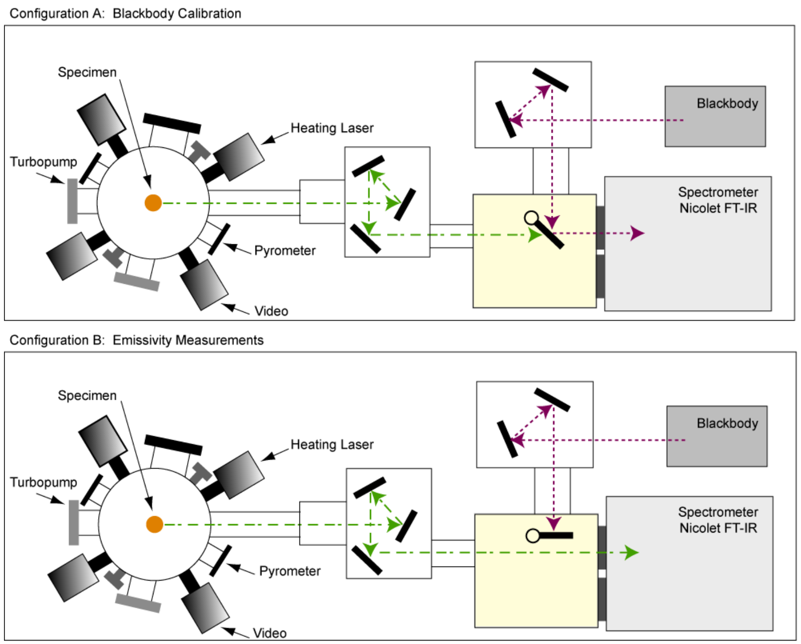
- This system measures the spectral emittance and calculates total emissivity of materials from 600°C to 3,000°C

- 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