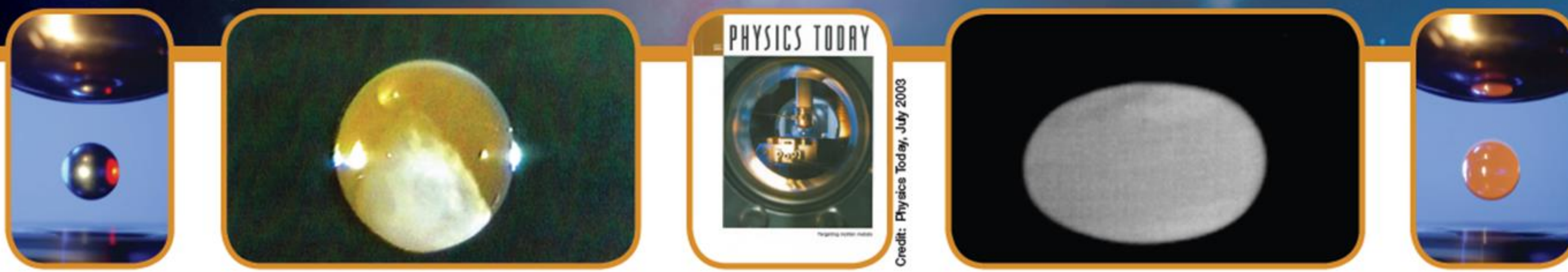
Marshall Space Flight Center

Electrostatic Levitation Laboratory



Measurement and Control of Oxygen Partial Pressure in an Electrostatic Levitator

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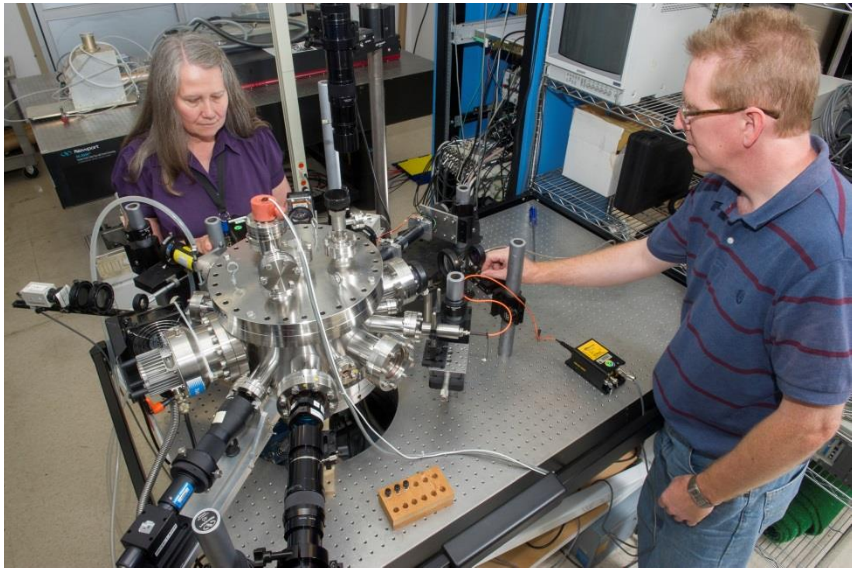
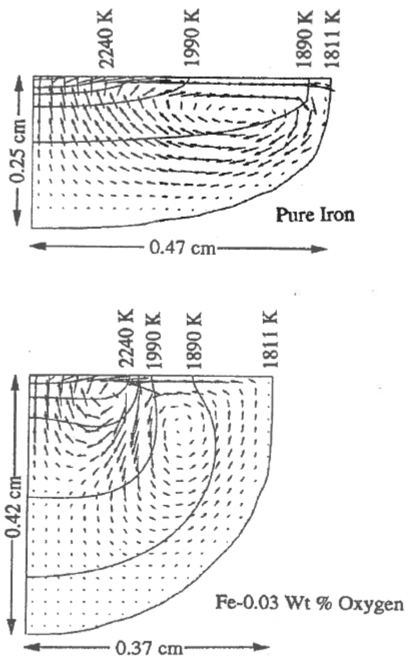
ESL Lab



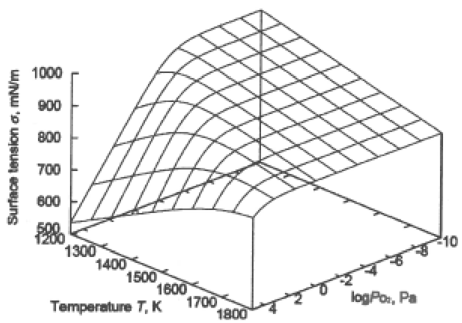
Trudy and Glenn working on the ESL Portable Chamber

- Michael SanSoucie (EM50)
- Jan Rogers (EM50)
- Paul Craven (EM50)
- Trudy Allen (METTS)
- Glenn Fountain (ESSSA)
- Curtis Bahr (ESSSA)

Need for Oxygen Partial Pressure Control



Calculated velocity and temperature fields for gas tungsten arc welding of pure iron and iron with 0.05 wt% oxygen[1]



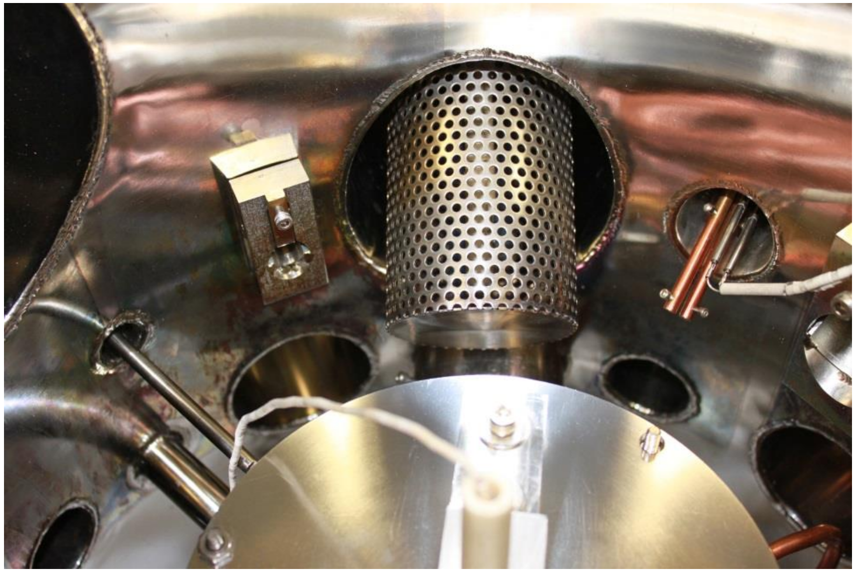
Measured relationship between surface tension, temperature, and p_{O_2} for molten silver[2]

- Supports microgravity principal investigators
  - An oxygen control system is planned for the European Space Agency (ESA) Electromagnetic Levitator on the International Space Station (ISS)
  - Also useful for study of oxides, which is the primary research focus of the Japan Aerospace Exploration Agency (JAXA) Electrostatic Levitation Furnace (ELF) that is planned to fly on the 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[3].
  - Causes a decrease in surface tension
- Oxidation can occur at very low p_{O_2}
  - Occurs in the ESL as low as ~ 1×10^{-24} bar p_{O_2}

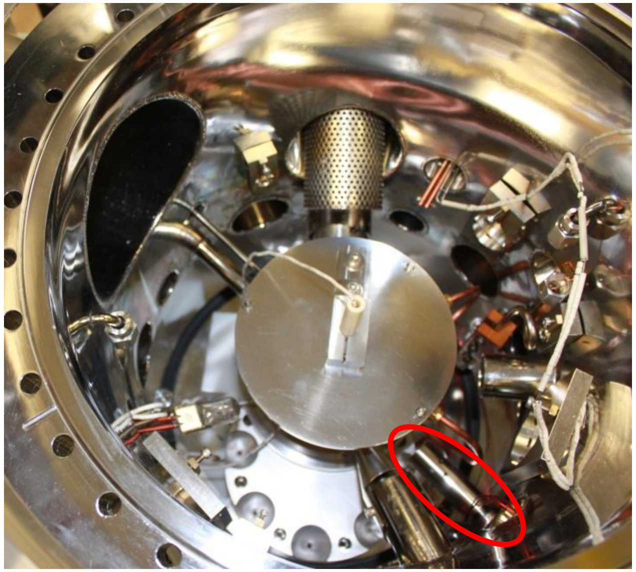
References:

1. DebRoy, T. and S.A. David, *Physical processes in fusion welding,* Reviews of Modern Physics, 1995, 67(1), p. 85-112
2. Ozawa, S., et al., *Influence of oxygen partial pressure on surface tension of molten silver,* Journal of Applied Physics, 2010, 107.
3. Ozawa, S., et al., *Influence of oxygen partial pressure on surface tension and its temperature coefficient of molten iron*, Journal of Applied Physics, 2011, 109.

Hardware



Oxygen Pump

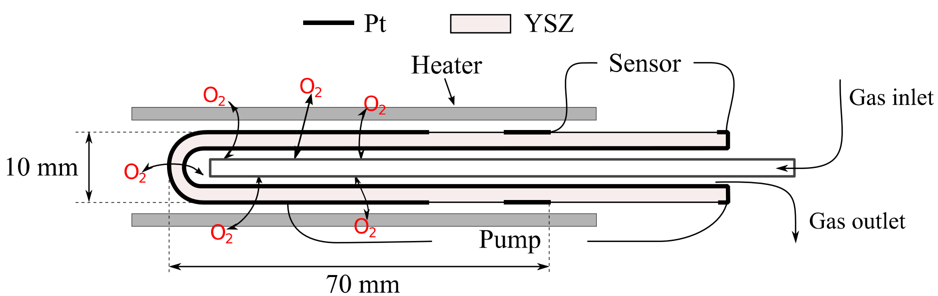


Oxygen Sensor

Controller

- Developed by Astrium North America
- Fabricated by Clausthal University of Technology (TU Clausthal)
- Michal Schulz (TU Clausthal) visited for 2 weeks in June to help with implementation
- Installed in the ESL Main Chamber

Oxygen Sensing

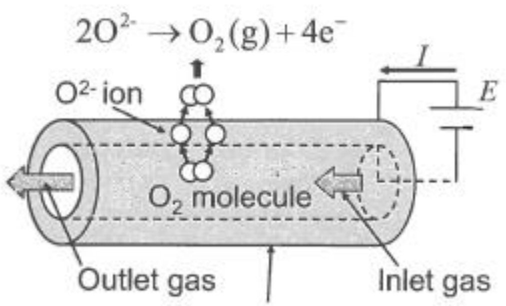


Schematic of oxygen ion sensor

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

- Potentiometric sensor
  - Determines the difference in oxygen activity in 2 gas compartments separated by an electrolyte
    - Yttria-stabilized zirconia (YSZ)
- Activity of gaseous compounds corresponds closely with their partial pressures
- p_{O_2} is calculated by using the Nernst equation
  - $E = \frac{RT}{4F} ln\left(\frac{p_{O_2}}{p_{O_2}^{ref}}\right)$
  - E is the electromotive force
  - R is the universal gas constant
  - F is the Faraday constant
  - $p_{O_2}^{ref}$ is the oxygen partial pressure of the reference gas (the lab atmosphere, in this case)
  - p_{O_2} is the oxygen partial pressure of the gas in question
- Must be operated above 500°C to enable sufficient ionic conductivity

Oxygen Pumping



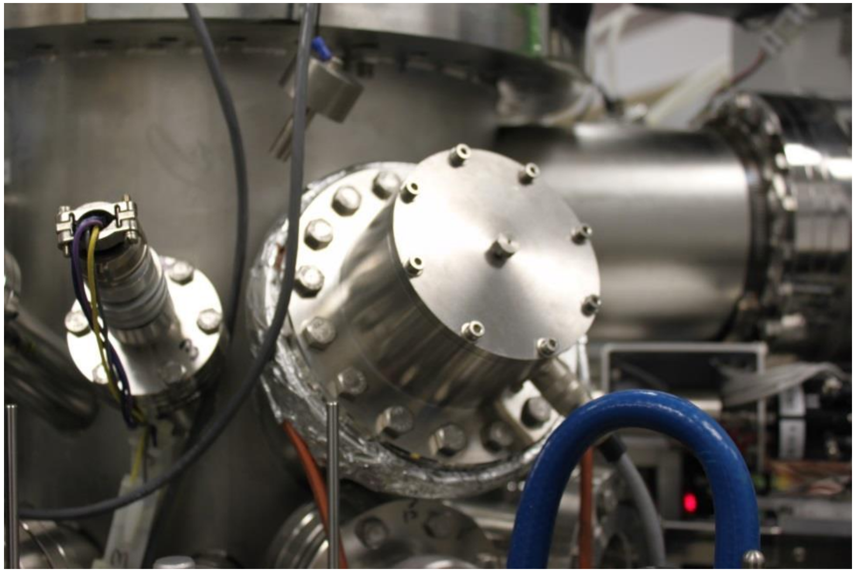
Schematic of oxygen ion pump

Oxygen molecules move through the YSZ tube from inside to outside when a difference in electrical potential is provided between the tube walls.

- Electric current is applied to the electrodes (Pt)
  - Charge 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 crystal lattice to form gaseous oxygen
- Must be operated above 500°C to enable sufficient ionic conductivity

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

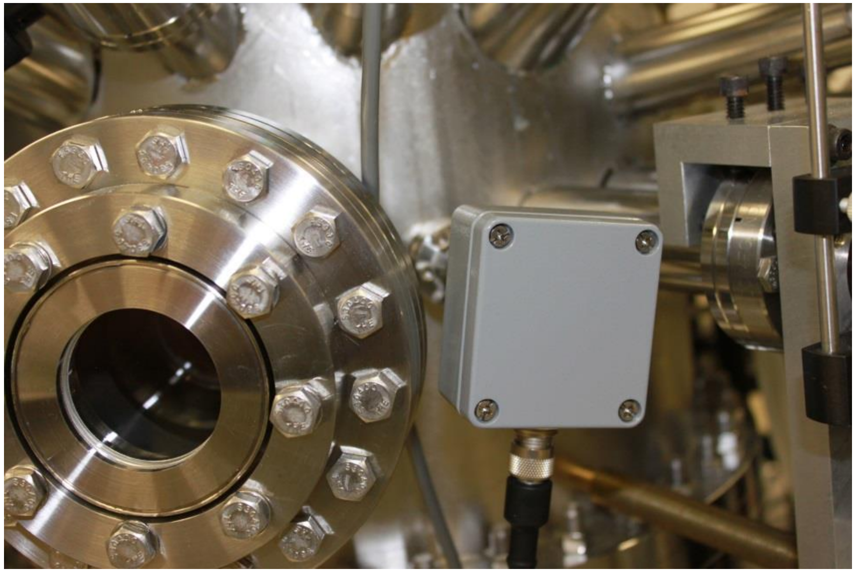
Results



Outside of the oxygen pump

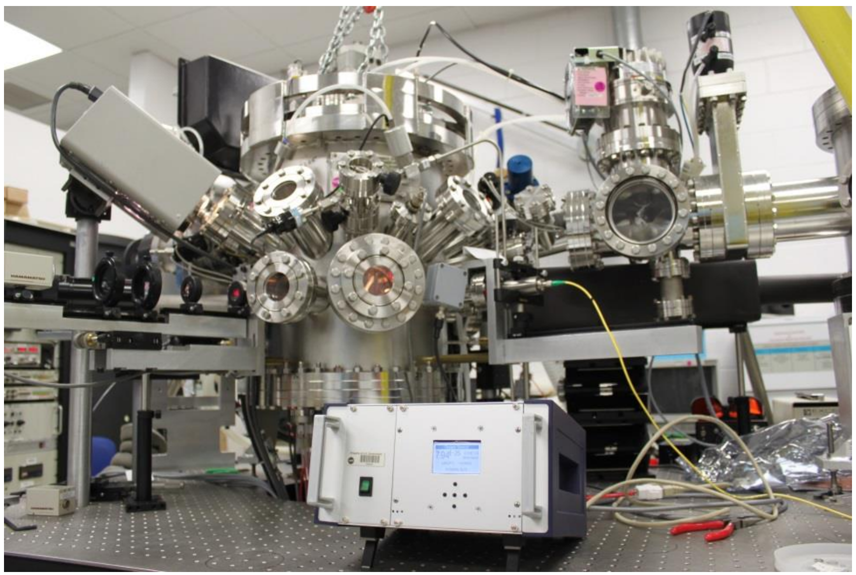
- Lowest achieved p_{O_2}: ~1x10^{-29} bar
  - Could potentially be improved by utilizing a bake-out lamp and long durations of pumping
- Highest achieved p_{O_2}: ~1x10^{-8} bar
  - Turbopump prevents the p_{O_2} from going much higher
  - Also raises the chamber pressure
    - More difficult to levitate
- Have observed a change in melting point of zirconium after high p_{O_2} pumping

Future Plans


Outside of the oxygen sensor

- Attempt to achieve higher p_{O_2}
  - Using an oxygen bottle
  - Potential space processing of oxides
- Attempt to achieve lower p_{O_2}
  - Long pumping times
- Calculation of the amount of oxygen absorbed
  - While sample is heated, integrate pumping power over the range of increase

Conclusions



View of the controller and ESL Main Chamber

- Have successfully integrated the system into the ESL and verified its function
- Increases the validity of thermophysical properties measurements
  - Provides defined, controlled conditions for measurement and processing
- Provides a resource for ground-based ISS microgravity research support

Questions

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