Emission Spectroscopy on Aluminum Wire Explosions in Different Atmospheres

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Outline

- introduction and motivation
- experimental setup
- visual observation
- I/U-characteristic
- spectra analysis
- temperature determination
- conclusion
Introduction and Motivation

Investigation of wire explosions:

- Low temperature plasmas…
  - … thermodynamic parameters reach extreme values
  - … investigation of chemical reactions of metals in different atmospheres
  - … spectroscopic investigation in absence of continuum radiation

- Different applications…
  - …plasma ignition of propellants
  - …production of metal nano particles
  - …creation of x-ray sources
Experimental Setup
**Visual Observation**

**Oxygen**
- White cloud with green/blue zone at the border
- Could be an Indicator that AlO is formed
- Emission much brighter than in air

**Carbon dioxide**
- White cloud with a green/blue zone
- Turns into a green/blue one (AlO)
- Intensity decrease very fast
Visual Observation

- White cloud turns in a green/blue one with great dimensions
- Emission is not so bright but it is visible for a long time

Air

- Very short process of light emission
- White cloud with purple border
- Originates from the excited aluminium atoms

Nitrogen and Argon
I/U-characteristic
- energy input

- Shapes and amplitudes of the voltage and current curves nearly independent from the atmospheres and for all atmospheres identical
- Energy input for all atmospheres the same
All spectra show the strong atomic lines of aluminium.

No aluminium oxide except in the first few spectra from the oxide layer.

AlH+ appears in all spectra independent from the atmosphere.
Spectra Analysis - air atmosphere

- First spectrum shows AlO, AlH+, Al atomic lines similar to all other atmospheres
- The atomic aluminium lines are in absorption
- Later the AlO B-X system is visible for a long time
Spectra Analysis - carbon dioxide atmosphere

- Atomic aluminium lines are in absorption
- CO system appears with unknown lines added
- Small signal of AIC at 570nm
- At the end of the process AlO B-X system is apparent
Spectra Analysis
- oxygen atmosphere

- First spectrum shows emission of atomic aluminium lines, AlO and AlH
- Al reaches absorption and the first AlO B-X system appears until the end of the process
Spectra Analysis - nitrogen atmosphere

- First spectrum similar to the first spectrum in other atmospheres
- AlN molecule emission may be apparent
Temperature Determination
- continuum temperature

- Mainly emitted from
  - solid surfaces
  - glowing particles (soot, oxides, …)
- Theoretical description: Planck‘s law for black body radiation

\[ L_{\lambda S}(\lambda, T) = \varepsilon \frac{c_1}{\lambda^5} \left( \frac{c_2}{\lambda T} \right) - 1 \frac{1}{\Omega_0} \]

- Simplest model: \( \varepsilon = \text{const} \) (grey body radiation)
Temperature Determination
- continuum temperature

- Grey body function was fitted to the spectra (ICT-BaM-Code)
- Integrated intensity distribution over the entire process
- Temperatures between 3400K and 3700K are a lower limit for gas phase temperature
Temperature Determination  
- gas phase temperature - Calculation of Diatomic Molecules

- wavelength = energy difference between excited and ground state
- intensity \( \propto \) transition probabilities and Boltzmann-factor

\[ \text{solution of Schrödinger-equation in Born-Oppenheimer-approximation} \]

- line profile

\[ \text{determined by the life time of the excited state} \]

\[ = \text{Lorentz profile} \]
Calculation of Diatomic Molecules

- Calculation of the Energy Levels

- Born-Oppenheimer-approximation:
  \[ E_{ges} = E_{el} + E_{vib} + E_{rot} \]

- Electronic energy: constant for a given electronic transition

- Vibrational energy: anharmonic model potential

- Rotational energy: symmetric top

\[ G(v) = \omega_e \left( v + \frac{1}{2} \right) - x_v \omega_e \left( v + \frac{1}{2} \right)^2 + y_v \omega_e \left( v + \frac{1}{2} \right)^3 + \cdots \]

\[ F(J, \Lambda) = B_e J(J+1) - (A - B_e) \Lambda^2 - D_e J^2 (J+1)^2 + H_e J^3 (J+1)^3 \]
Calculation of Diatomic Molecules

- Calculation of the Line Intensity

- line intensity:
  \[ I_{nm}^{em} = N_n h c \nu_{nm} A_{nm} \]

- population density:
  \[ N_n = N d u e^{\frac{hc E_{mol}}{k_B T}} \]

- energy of the transition:
  \[ E = h c \nu_{nm} \]

- Einstein-Coefficient for spontaneous emission:
  \[ A_{nm} = \frac{2}{3} \cdot \frac{8 \pi^3 \nu_{nm}^3}{\varepsilon_0 c^3 h} \cdot |D_{nm}|^2 \]

- dipole operator matrix element:
  \[ |D_{nm}|^2 = |D_{mn}^{el} (R_{v''},v')|^2 q_{v'',v'} S_{J'',J'} \]
Temperature Determination
- gas phase temperature

- Aluminium monoxide B-X system was analysed (fit calculated to experimental spectrum)

- The higher the temperature the more the rotational lines are excited and the slope between 490 nm and 507 nm is weaker

It will be sufficient to fit only for this range because of self-absorption processes
Temperature Determination
- gas phase temperature

- AlO was first formed in the middle of wire explosion process
- Temperatures were between:
  - 9500K and 6900K in oxygen
  - 9200K and 8600K in air
  - 11000K and 8800K in CO$_2$
- Temperature of the cool down phase
- Increase of temperature at the end

-calculated spectrum does not correspond well with the experimental spectrum
Conclusion

- aluminium wire explosions were investigated in different atmospheres
- First results of the experiments were presented
- High-speed videos give hints for the formation of aluminium monoxide
- I/U-characteristic shows that the input energy was independent from the atmosphere and equal for all measurements
- Analysed UV/VIS spectra show time resolved formation of atomic lines and diatomic molecules
- Continuum temperature was calculated but only for integrated intensity
- Gas phase temperature were determined for the cool down phase of the plasma
Thank you for your attention