Investigations of Novel Plasma Spray Processes by Optical Emission Spectroscopy (OES)

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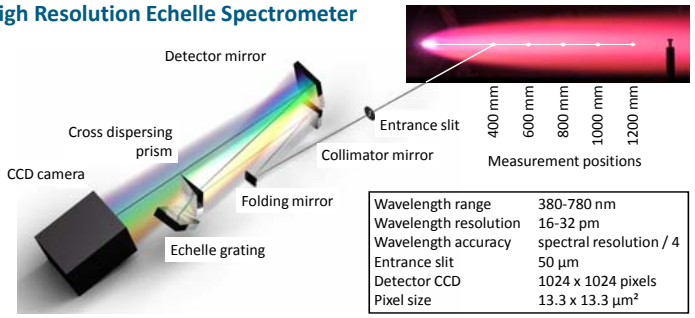
For thermal barrier coating systems (TBCs), there are two major development directions: the improvement of the materials on the one hand and the investigation of new manufacturing techniques on the other hand. They are closely related to each other and must be both considered correspondingly [1]. This poster focuses on the investigation of two novel manufacturing processes for TBCs by optical emission spectroscopy (OES).

Plasma Spray – Physical Vapor Deposition

Plasma Spray-Physical Vapor Deposition (PS-PVD) is a new technology operating at low pressure and high plasma power. At such condition, vaporization even of high-melting oxide ceramics is possible enabling the formation of columnar structured coatings from condensates and nano-sized clusters. These unique plasma conditions were characterized by OES [2] to improve the understanding of the process.

High Resolution Echelle Spectrometer

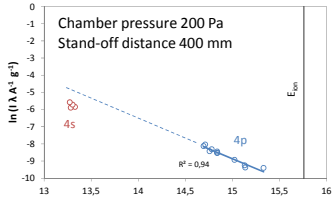


Wavelength range	380-780 nm
Wavelength resolution	16-32 pm
Wavelength accuracy	spectral resolution / 4
Entrance slit	50 µm
Detector CCD	1024 x 1024 pixels
Pixel size	13.3 x 13.3 µm²

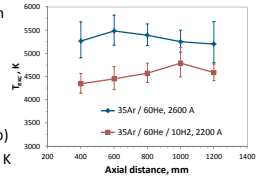
Echelle spectrum of a tungsten lamp

Courtesy: LTB Lasertechnik Berlin

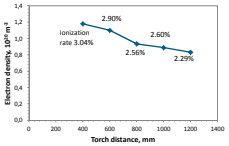
Electron Temperatures by Boltzmann Plots



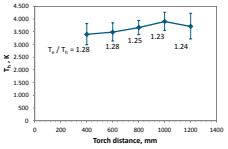
- 15 Ar I lines between 549.59 nm / 751.47 nm
- 4 lines with lower energy levels (4p – 4s)
- 11 lines with higher energy levels (4d, 6s, 5d, and 6d – 4p)
- $T_{exc,h}$ = 5065 +466/-394 K represents T_{Saha} and T_e



Electron Densities and Ionization Rates by Stark Broadening Analysis of H_β Line



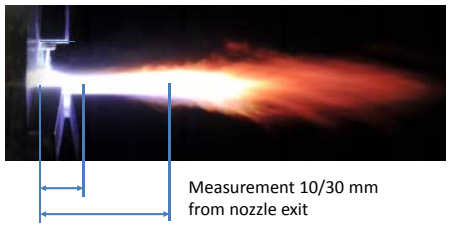
Temperature of Heavy Particles and Non-Equilibrium Parameter by Doppler Broadening Analysis of H_β Line



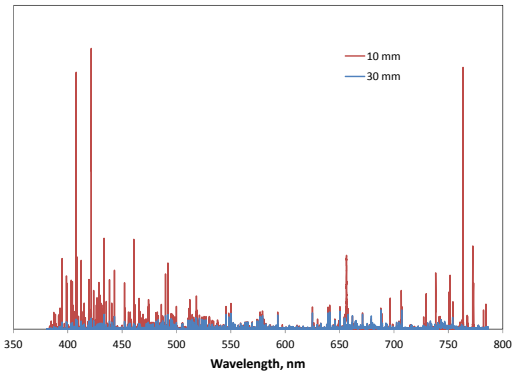
- At PS-PVD conditions recombining plasma with a low density and degree of ionization
- Hydrogen admixture affects the plasma enthalpy due to initial consumption and later release of dissociation energy.
- Slight deviation from LTE

Suspension Plasma Spray

Suspension plasma spraying (SPS) is a novel method to process submicron-sized feedstock powders which are not sufficiently flowable to feed them in dry state. Such finely grained materials are generally prone to partial evaporation under plasma spray conditions. Furthermore, this evaporation can be inhomogeneous so that the stoichiometry of the deposits might be affected. This was quantitatively investigated by OES [3].



Measurement 10/30 mm from nozzle exit



Emission line intensities are dependent on
- density and
- temperature

of gas species

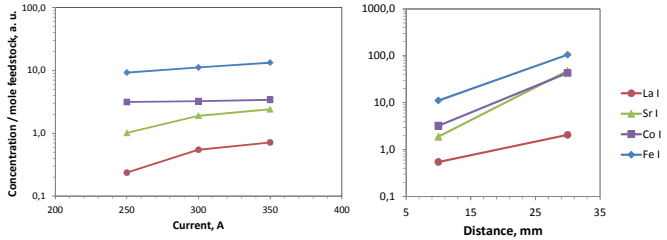
Absolute intensity I_{jk} of a spectral line emitted by the plasma due to the transition from an excited state j to a lower energy state k

$$I_{jk} = \frac{L\,h\,c}{4\pi\,\lambda_{jk}} A_{jk}\, n_{tot}\, \frac{g_j}{Z(T)}\, e^{-E_j/k_B T}$$

E_{photon} n_j p_j

L	Emission source depth
h	Planck's constant 6.63 × 10^{-34} $J\,s$
c	Velocity of light 2.99 × 10^{8} $m\,s^{-1}$
A_{jk}	Transition probability
n_{tot}	Total density of species
g_j	Statistical weight (degeneracy) of the excited level j
λ_{jk}	Wavelength of emission
$Z(T)$	Partition function (sum over states)
E_j	Energy of excited level j
k_B	Boltzmann constant 1.38 × 10^{-23} $J\,K^{-1}$
T	Excitation temperature
E_{photon}	Energy of a photon
p_j	Probability of Boltzmann distributed excited level j
n_j	Density of emitting species

Lanthanum-Strontium-Cobalt-Ferrite $La_{1-x}Sr_xFe_{1-y}Co_yO_{3-\delta}$ (LSFC)
Molar volumetric concentrations related to the molar fraction in the feedstock



- Effects of species concentration and temperature on peak intensities distinguished.
- Inhomogeneous evaporation of LSCF feedstock constituents confirmed.
- Evaporation still in progress up to the largest investigated spray distance of 30 mm.

[1] G Mauer, MO Jarligo, DE Mack, R Vaßen, *Plasma Sprayed Thermal Barrier Coatings: New Materials, Processing Issues and Solutions*, J. Therm. Spray Technol. **22** (2013) 646-658.
[2] G Mauer, R Vaßen, *Plasma Spray-PVD: Plasma Characterization and Impact on Coating Properties*, J. Phys.: Conf. Ser. **406** (2012) 012005.
[3] G Mauer, N Schlegel, A Guignard, R Vaßen, O Guillon, *Effects of Feedstock Decomposition and Evaporation on the Composition of Suspension Plasma Sprayed Coatings*, J. Therm. Spray Technol., **24**, (2015) 1187-1194.