Optical Emission Spectroscopy during Anodic Arc Deposition of Dielectric Films

Robert Werberger, Ludwig Decker, Stefan Saager, Bert Scheffel

Fraunhofer Institute for Electron Beam and Plasma Technology (FEP)
Winterbergstr. 28, 01277 Dresden, Germany

Introduction

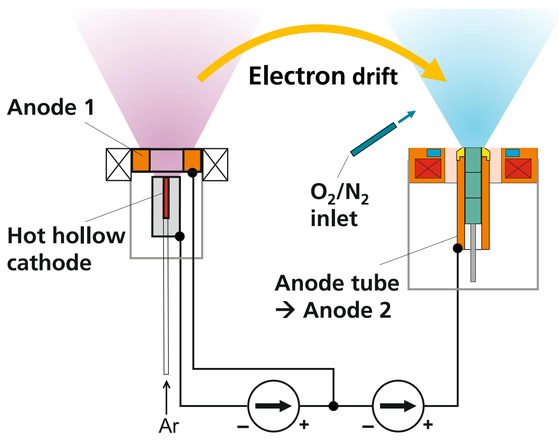
- Thin film deposition is a crucial technology for optoelectronic applications, such as solar cells.
- Building on previous developments in Japan, known as Reactive Plasma Deposition (RPD) [1], the anodic arc deposition technique was independently developed at FEP in combination with a hollow cathode [2].
- Anodic arc deposition provides a gentle physical vapor deposition (PVD) method, offering higher ionization rates and the absence of high-energy particles compared to magnetron sputtering [3].
- This study demonstrates the extension of anodic arc deposition to the evaporation of electrically insulating materials, including Al_2O_3, MgO, SiO_2, and Si_3N_4.
- The influence of anodic discharge current (25–70 A) and gas flows (O_2/N_2: 0–200 sccm) on plasma properties and the transmission of deposited layers is systematically investigated.
- Optical Emission Spectroscopy (OES) is employed as a non-invasive diagnostic tool for plasma diagnostic.

Design and Functionality of Anodic Arc Deposition in Combination with a Hollow Cathode Arc Discharge

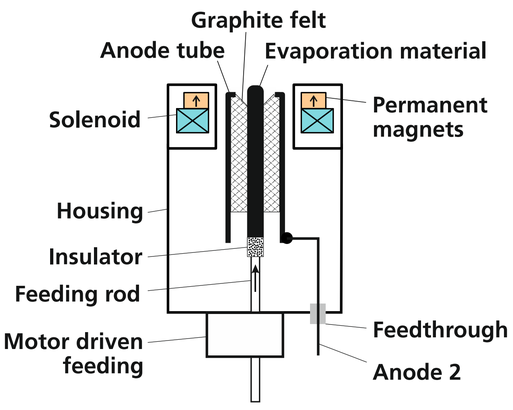
Hollow cathode arc as electron source

Anodic arc deposition

- Electrons drift from the hollow cathode toward the anode tube.
- Magnetic fields focus the electrons onto the evaporation material.
- The evaporation material heats up, evaporates, and interacts with the incoming electrons. → The resulting vapor ionizes, leading to plasma ignition.

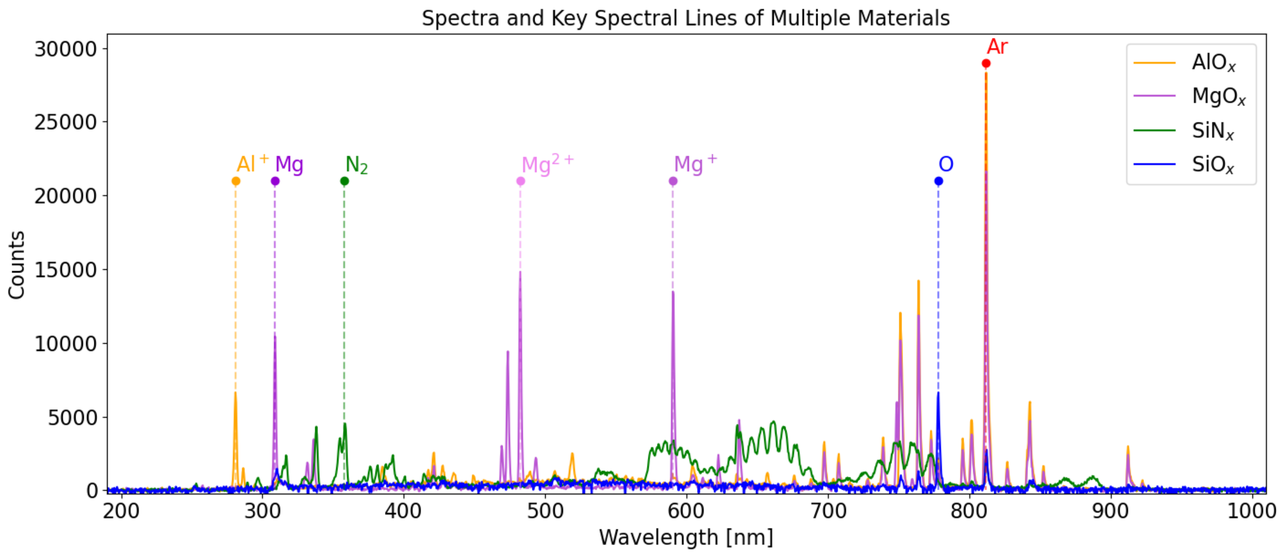


Principle and electrical circuit of the anodic arc evaporation in combination with a hollow cathode

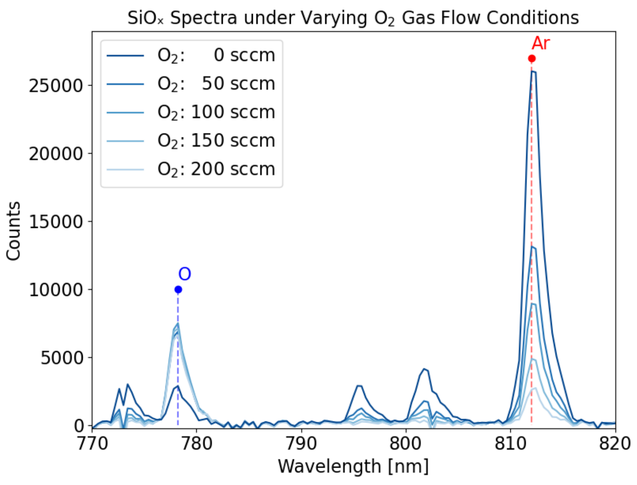


Scheme of the anodic arc evaporator

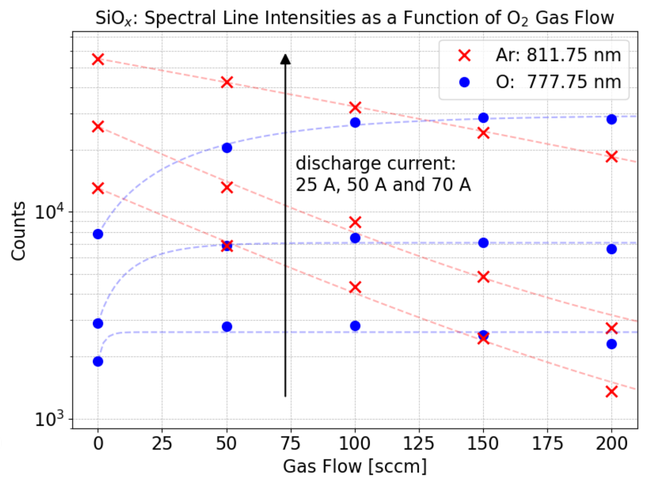
Plasma Diagnostic with Optical Emission Spectroscopy



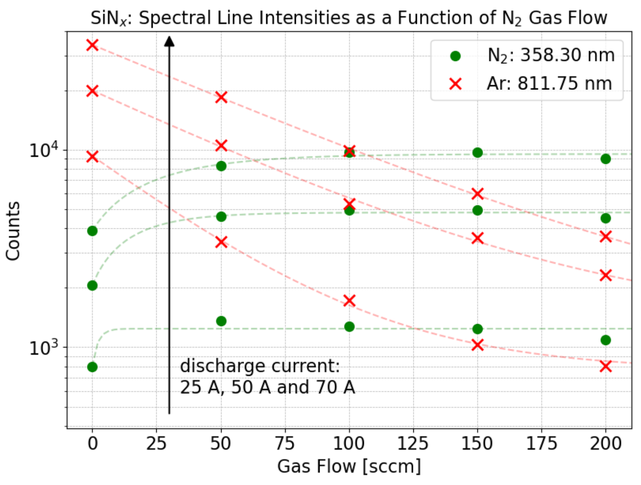
- In the emission spectrum of the plasma, individual elements can be clearly identified by their characteristic spectral lines.
- Silicon could not be unambiguously detected in the emission spectrum.
  → Its spectral lines may be overlapped by those of other particles or lie outside the measurement range.
- The spectral lines of the working gas (Ar) are observed in all measurements.

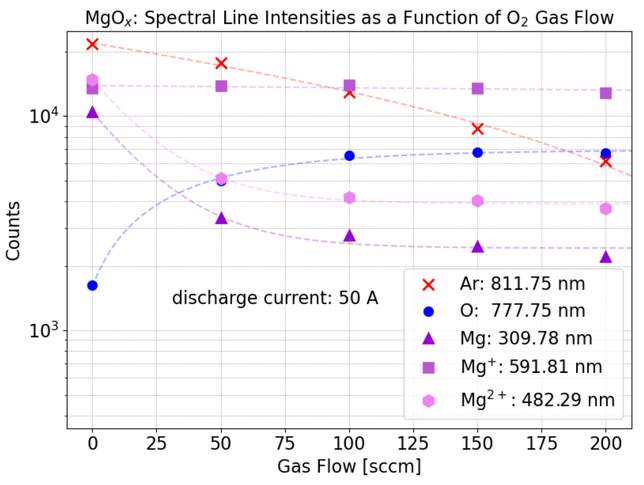


- The intensity of the Ar spectral lines decreases continuously with increasing O_2 gas flow. → A possible explanation for this behavior could be Penning ionization.
- After an initial jump, the O spectral line intensity remains constant.
- This behavior is also observed with the introduction of N_2 gas.



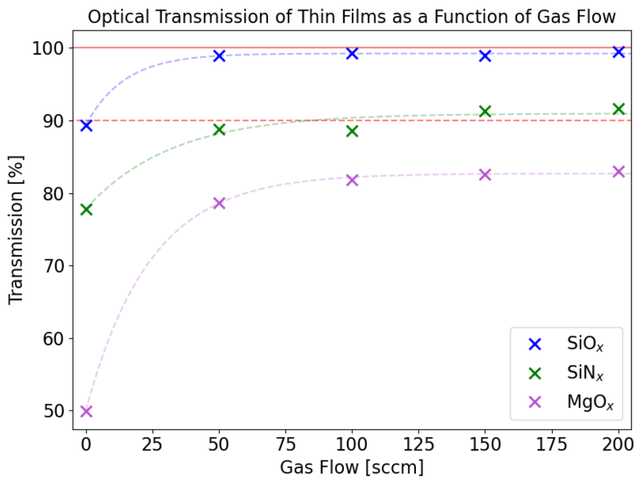
- The spectra of SiO_x, SiN_x, and MgO_x exhibit an exponential decay of the Ar spectral line and a saturation of the O or N_2 spectral line with increasing the gas flow.
- Overall, the spectral line intensities increase at higher discharge currents.





- The spectra of MgO_x reveal the presence of Mg ions.
- The intensities follow a similar trend to those of SiO_x and SiN_x, with the exception of Mg^+, which remains constant.
- This behavior is consistent by MgO_x across discharge currents ranging from 42 to 70 A.

Anodic Arc Deposition of Transparent Layers



- The transmission values were averaged over the wavelength range of 300 to 1200 nm.
- Introducing O_2 or N_2 gas increases the transmission of all layers until saturation is reached.
- For SiO_x and SiN_x, a transmission of over 90% was achieved.

Summary and Outlook

- The deposition of transparent layers of the insulating materials SiO_x, SiN_x, and MgO_x was successfully achieved for the first time using anodic arc deposition.
- Plasma ignition and operation were stable and reproducible for these materials. However, Al_2O_3 requires additional experiments to achieve similar results.
- Key spectral lines of the elements were identified via optical emission spectroscopy and can be utilized for process monitoring. Further investigation is required to locate the spectral lines of silicon.
- The behavior of the spectra at different discharge currents and gas inlets was analyzed and presented.
- A transmission value of over 90% was achieved for SiO_x and SiN_x layers.

Contact
Robert Werberger, M.Sc.
robert.werberger@fep.fraunhofer.de
Winterbergstraße 28
01277 Dresden

LinkedIn

References:

[1] Iwata *et al.*, Thin Solid Films, 480–481, 199–203 (**2005**), DOI 10.1016/j.tsf.2004.11.072

[2] Scheffel *et al.*, Surface and Coatings Technology, 477, 130305 (**2024**), DOI 10.1016/j.surfcoat.2023.130305

[3] Kitami *et al.*, Japanese Journal of Applied Physics, 54, 01AB05 (**2015**), DOI 10.7567/JJAP.54.01AB05

Essential results were obtained in public project „LUMINOSITY“. This project has received funding from the European Union's Horizon Europe Research and Innovation Program under grant agreement No. 101147653

Funded by the European Union

Presented at V2025, Dresden, GERMANY