Insight about magnetron sputtering using Life Cycle Assessment (LCA)

Antoine Merlo, PhD student
Grégoire Léonard, professor

Materials Science and Engineering Congress (MSE) 2020
24/09/2020
Presentation structure

- Introduction
- LCA methodology
- Magnetron Sputtering and LCA
- Considerations on metal consumption
- Considerations on energy consumption
- Possible improvements
- Conclusions and perspectives
Introduction

- Thin films are becoming more prevalent than ever

... and there is a need for environmental accountability!

- Applying assessment techniques to deposition processes
- Life cycle assessment (LCA) on magnetron sputtering

1 Reve news: https://www.evwind.es/2020/07/05/in-2019-the-solar-pv-market-increased-an-estimated-12-to-around-115-gw/75561
Life Cycle Assessment

- Takes into account emissions over the whole life cycle
- From extraction to end-of-life
- Use standardised by ISO (ISO 14040 & ISO 14044)
- 4 phases of study
Life Cycle Assessment

Goal and scope definition

Inventory analysis
  List emissions \( E_i \)

Impact assessment
  Apply characterisation factor: \( I_i = CF_i \times E_i \)

Interpretation
Magnetron sputtering and LCA

Magnetron sputtering

- Deposition technique
- Voltage applied to target in vacuum chamber
- Plasma bombardment on target
- Film growth on substrate

Ar
Reactive gases

During process, almost no emissions, but …
Magnetron sputtering and LCA

- Target production can have a huge impact
  - Metal extraction and refining can be energy intensive and have a lot of emissions
  - Target manufacture can be an impactful process

- Very high energy consumption per g deposited!
  - Impact depends a lot on electricity production mix

- Inert and reactive gases production usually have a negligible impact
Considerations on metal production

- Rarer metals ➔ Higher impact!
- Toxicity linked to metal production
- Inefficient in MS: only part of the target is used (race tracks)
- Waste on vacuum chamber walls
Example: rare metals production

Relative GWP and Human Toxicity of Cu, Ag and Au

Element abundance in Earth’s crust:
Cu : 60 ppm
Ag : 0.075 ppm
Au : 0.004 ppm

---


Considerations on energy consumption

- Pumping is not a negligible part of energy consumption

- High energy needed to maintain plasma and sputtering

- Depending on the country’s electricity mix, impacts can vary

Example of energy repartition in a lab/experimental apparel (Process Not Optimised)
Energy consumption example: Cr film

Electricity consumption of Cr deposition processes (kWh)

- Magnetron Sputtering
- Electro plating

Functional unit: 20µm Cr film on 1 m²
Possible improvements

- Reduce metal/energy consumption and impact
  - Careful chamber design: adapted pumping system, magnetic field to increase flow from target to substrate, …
  - Use of recycled materials or more abundant elements for the targets to limit impact
  - Improvements to deposition rate (target heating, …)

- Enhance film properties to improve efficiency in the use phase (HiPIMS, structured materials, …)
Impact mitigation with recycled metal feed
Impact mitigation with recycled metal feed

Example applied to chromium deposition (Assumptions)

- Going from belgian mix (~50% nuclear, ~25% natural gas, ~15% renewables, ~10% others) to energy coming fully from wind power, as an extreme example

- Use of recycled metallic chromium (recycling is assumed to be ~0.55 times as impactful as production from ore)

- Inventory from assumptions, data from Ecoinvent 3, impacts from ReCiPe 2016 method (Endpoints, humanitarian)
Potential mitigation: chromium deposition

Endpoints impact repartition of chromium deposition via magnetron sputtering

- Magnetron sputtering, belgian mix
- Magnetron sputtering, wind power
- Magnetron sputtering, wind power & recyc. Target
Conclusions

- LCA: powerful tool for environmental decision making

- For MS practitioners:
  - Prefer abundant, low-impact elements
  - Thinner films = lower impact
  - Optimise pumping, and chamber design

- Need for a metal recovery loop implementation

- Software for MS modelling could help make environmental decision by incorporation LCA directly
Perspectives

- Combine LCA with other assessment techniques (Techno-Economic analysis and social assessment p.e.)

- Study the use phase to make a more nuanced study

- Assess metal production in a more accurate way, and include recycling

- Apply the assessment techniques to the materials and techniques studied by PULSATEC partners
Thank you for your attention!

Any questions?