Magnetic field strength as a variable in optimizing magnetron sputtering processes

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Objectives

• Look at the strength of the magnetic field as a variable to investigate its effect on heat flux and deposition rate for a specific process.
• Find the impact of varying magnetic field strength on heat and particle flux uniformity.
• Determine if target temperature changes relative to magnetic field strength and if it does change, to what degree it affects heat flux.
Introduction

• The interaction between the magnetic field and the plasma is complex, it depends on several processes in a nonlinear manner.
• The components of the total heat flux at the substrate are various: energetic neutrals, high energy electrons, plasma irradiation, hot bodies.
• Depending on the application, one may look to increase or decrease the heat flux to tailor the properties of the deposited film.
Heat flux in magnetron sputtering

- **Source**
- **Sink**

**Plasma**

- **Charged particles**
- **Sputtered and reflected neutrals**
- **Gas heating**
- **Plasma radiation**

**Substrate**

- **Film-substrate conduction**
- **Thermal and athermal diffusion, nucleation**
- **Heat of condensation**

**Holder**

- **Substrate-holder conduction**
- **External heating**
Experiments

1. Measure heat flux using integrated sensor at several locations along the substrate.
2. Measure deposition rates at the same locations where heat flux was measured.
3. Measure target temperature during deposition

- Three throw distances
- XY survey (72 points on the surface of the substrate)
- Magnetic field characterization
- Target temperature measured at two locations
Chamber and process conditions

- 177 L semi-rectangular chamber
- Target = Silver (hardly eroded)
- Pressures = 4.3 and 1 Pa
- Current = 1 A
- Throw distances = 7, 10 and 13 cm
- Sampled area = 144 cm²
Heat flux sensor

Due to geometrical constraints, only the region marked as blue was sampled.
Magnetic field
- Two resistance temperature detectors (RTD) were mounted on each side of the target.
- The cathode temperature was in the range of 14-16 ºC at the beginning of each measurement.
Results

- Voltage as a function of the magnetic field strength
Heat flux 4.3 Pa

13 cm throw distance

7 cm throw distance
Heat Flux 1 Pa

13 cm throw distance

7 cm throw distance
Deposition Rate 4.3 Pa

13 cm throw distance  7 cm throw distance
Deposition Rate 1 Pa

13 cm throw distance

7 cm throw distance
Integrated deposition rate and heat flux
Target Temperature

![Graph showing the relationship between magnetic field strength and temperature for 1 Pa and 4.3 Pa. The temperature increases with magnetic field strength for both pressures, with a slight decrease after reaching a peak.]
Summary and Conclusions

- The heat flux at the substrate is reduced by decreasing the magnetic field strength with no reduction of the deposition rate. The effect is more noticeable at the low throw distance and low pressure.
- Heat flux uniformity strongly depends on the throw distance and magnetic field strength. A detailed balance of these parameters is key to optimizing the process.
- Deposition rate slightly increases for lower magnetic field strengths (using our cathode design).
- Target temperature does not significantly contribute to the total heat flux (Ag in Ar).
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