Multifunctional substrate holder for a film-deposition system

Many of the Institut NÉEL's research projects require constructing specialist equipment in-laboratory, to precise specifications. We describe here a technical development that has greatly improved a system used for high-rate deposition of thick magnetic films onto silicon substrates by DC sputtering. These films are studied for their functional magnetic properties and their integration into novel microsystems.

In Direct Current (DC) sputtering (*pulvérisation*), a "target" material, made from a metal or metallic alloy, is bombarded by charged plasma ions (*e.g.* Ar^+). This bombardment ejects metal atoms from the target, which then deposit on a substrate positioned nearby. We have designed and built a greatly improved substrate holder (Fig. 1) for an existing sputtering system, to enhance possibilities for growth and integration of functional magnetic films.

The specifications: A first requirement was to heat 4 inch (10 cm) diameter silicon substrates *uniformly* over their entire surface, up to temperatures of 800 °C in vacuum or under low pressures of argon or nitrogen. A second requirement was to be able to rapidly cool the substrate from high temperature, at the end of film growth or post-deposition annealing. This is in order to control the film's microstructure (grain size, etc.) and to manage mechanical strain. Also, the distance between the substrate and the target must be adjustable, and the substrate must be rotatable during deposition to achieve homogeneous composition and thickness. Finally it should be possible to bias the substrate at up to -300 Volts (2 Amps current) to enable film etching, which required adding baffles to prevent stray deposition producing short circuits between parts at -300 V and grounded parts.

Our greatest constraint was to fit this new, relatively large substrate holder in the limited space of an existing growth chamber yet be able to rotate it within the chamber to achieve three working positions (90 degrees apart) for substrate loading, film deposition, and annealing, respectively. To respect all these specifications, we had to overcome many technical challenges.

The heater component: The substrate support (Fig. 2) is made from a block of the Molybdenum alloy "TZM" (Mo with 0.5% Titanium and 0.08% Zirconium), a material that represents a good compromise as concerns mechanical resistance at high temperature, thermal conductivity, recrystallization temperature and evaporation under vacuum.

The 240 V, 8 A heating element was made from tungsten wire. We shaped the wire into the form of a coiled spring at 300 °C, where tungsten becomes ductile. The coil was then inserted into sections of alumina tubes for insulation. Alumina (Al_2O_3) is compatible with tungsten up to 1900 °C, has excellent electrical insulating and heat conducting properties, and its relatively high emissivity optimizes radiative heat transfer to the TZM block. This heating element is mounted inside the TZM block (see Fig. 2). Extensive testing was done to determine the best operating temperature of the wire for safe, prolonged operation (1500° C) and the optimum length of wire (15 m) to match the power supply's impedance at this temperature.

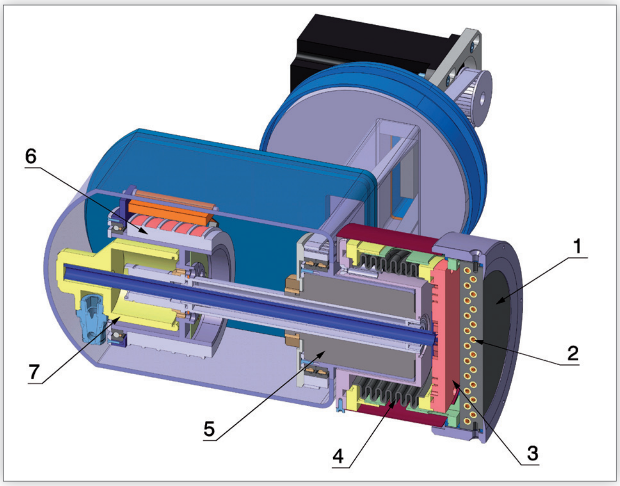

Fig. 1: *Section drawing of the substrate holder. During film deposition, a 4 inch diameter silicon substrate is attached to the outer surface of the molybdenum alloy block, at the right of the image.*

- ***1:*** *Molybdenum alloy block.*
- ***2:*** *Heating element.*
- ***3:*** *Copper flange.*
- ***4:*** *Bellows.*
- ***5:*** *Ferrofluidic vacuum rotary feedthrough.*
- ***6:*** *Slip-rings for power, thermocouple and bias voltage.*
- ***7:*** *Water-supply rotary swivel.*

The fast cooling system: This is based on the original idea of using a copper "flange and bellows" unit filled with cold water. To cool the TZM block rapidly, the water pressure is increased to expand the bellows (*soufflet*), thus bringing the flange (*bride*) into sudden contact with the TZM block.

We chose a bellows made up of four concentric thin walls, which increases the deformability and reliability of the bellows, while keeping it rigid enough not to stretch during evacuation of the chamber. The water circulating in the bellows also serves to screen the radiation coming from the hot TZM block, thus protecting vulnerable parts such as the electrical connections and the magnetic ferrofluidic joint which seals the rotation-axis.

The upper face of the TZM block was honed to a matte surface to increase its heat radiation to the attached substrate. The opposite face, which comes into contact with the copper cooling flange, was highly polished to achieve maximum planarity and a bright surface to limit downward radiation. *An important detail:* We milled the copper flange under pressure to compensate for deformation of its surface at working pressure. Thus it is perfectly flat when the pressure forces it into contact with the TZM block (otherwise, only the centre would be in contact).

The improved sputtering system is being used for studying a range of functional magnetic materials (hard, soft, magneto-caloric) in the framework of both EU and industrial projects.

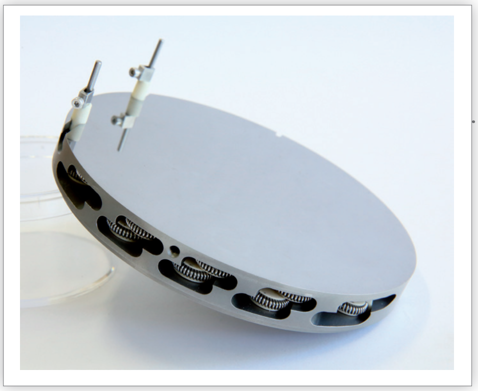

Fig. 2: *The molybdenum alloy block, seen upside down, with the tungsten coil heating element visible through the holes. The highly polished under surface minimizes heat radiation into vulnerable elements underneath it. The substrates are attached to the top surface (the opposite surface, not seen in this photo).*

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