Fabrication of Bolometer Sensors on very Thin YSZ Substrates

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In the frame of ITER, the international consortium developing the world's largest Tokamak to prove the feasibility of fusion as a large-scale and carbon-free source of energy, CSEM is manufacturing the bolometer-sensors necessary to monitor the plasma during operation. Despite the fact that these devices need be manufactured on very unusual substrates–20-micrometer thick yttrium-stabilized zirconia–standard microfabrication technologies have been used owing to the development of dedicated handling tools and a suitable temporary bonding process.

In the quest for sustainable energy production, an international joint experiment has been launched, called ITER. The goal is to build a magnetic fusion reactor which will be capable of delivering net energy for the first time, paving the way to the power plants of tomorrow. The device consists in a toroidal vacuum chamber in which a very high temperature plasma is formed and confined. This plasma will host the fusion reactions between deuterium and tritium nuclei and produce energy in the process.

In order to control the extreme conditions necessary for the reactions to take place, a very large battery of monitoring systems has to be developed. One of them is the bolometer diagnostic, which consists of about 100 5-channel bolometer sensors, the purpose of which is to measure the profile of total radiated power emitted by the plasma in the part of the electromagnetic spectrum situated between X-rays and infrared. Each sensor is basically a thin membrane, with on one side a metallic radiation absorber, and on the other side thin film resistors. The latter are connected in a Wheatstone bridge, enabling the detection of any temperature variation through the monitoring of the resistance value.

Prototypes of bolometer sensors are fabricated at CSEM (Figure 1). A first challenge is linked to the type of substrate material to be used: The 20-µm thick membranes must be made of YSZ (yttrium-stabilized zirconia), which is extremely brittle. The 100 x 100 mm^2 YSZ thin foils cannot be processed as such by the regular pieces of manufacturing equipment. It is thus necessary to temporarily bond them on carrier wafers that can be handled by the different machines. A bonding process compatible with all the fabrication steps has thus been developed, together with the necessary tooling to manipulate and release the thin substrates.

During the manufacturing sequence, the bonding and release of the YSZ foil must be done twice, since processing is performed on both sides. On the first, the resistors are fabricated, which requires the sputtering of a platinum film, and its subsequent patterning by photolithography and dry etching. On the second side, the absorbers are realized by electrodeposition of gold in photoresist molds, which entails first the deposition of different adhesion, barrier, and seeding layers. The choice of materials and processes to apply is critical as the devices must survive thermal cycling. Long-term stability of the interfaces between YSZ and the absorbers must be ensured. Another challenge for the manufacturing of the bolometer sensors is the thickness of the absorbers, which is more or less comparable to that of the YSZ substrate. Stress management in the different layers is hence of utmost importance in order to obtain a flat device after the final release. As a last step, the substrates are cut by laser, which enables not only the dicing into individual sensors, but also the punching of round holes necessary for the mounting of the membranes into the measurement system.

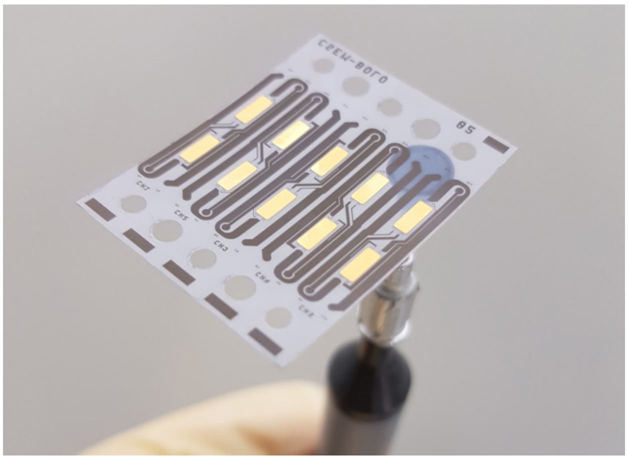

Figure 1: 5-channel bolometer sensor (25 x 33 x 0.02 mm^3).

The finished devices must meet stringent specifications. In addition to surviving harsh conditions (thermal cycling at 400°C), electrical stability of the Wheatstone bridge is mandatory. The value of each resistor is hence measured at 4 temperatures, and the temperature coefficient of resistance (TCR) is derived from the measurements. In case the absolute value of any individual resistor is out of specification, laser trimming is applied on the Pt meander to tune resistance. Special features have been included in the device layout for that purpose, enabling a modification of the electrical path length (Figure 2).

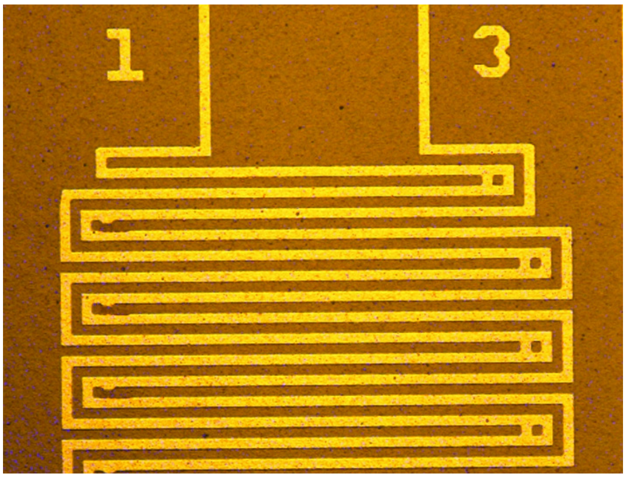

Figure 2: Detail of meanders with laser-trimmed features on the left.

This development is commissioned by the European Joint Undertaking for ITER and the Development of Fusion Energy (or F4E, Fusion for Energy).