Bolometer for Plasma Diagnostics in ITER Tokamak

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A large international consortium is developing the world's largest tokamak to prove the feasibility of fusion as a large-scale and carbon-free source of energy. The building of this huge infrastructure by 35 nations is taking place in Saint Paul-les-Durance in the south of France. The first plasma is expected by the end of 2025. In that frame, CSEM is manufacturing bolometer-sensors which are the key components of one of the 50 diagnostic systems necessary to monitor the plasma during operation. The bolometers are manufactured on very thin ceramic substrates. The produced prototypes withstand thermal cycling and meet the electrical specifications set for the application. The delivered sensors still need to be submitted to irradiation testing in order to verify their suitability for the Tokamak environment.

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. A schematic view of the reactor is shown in Figure 1.

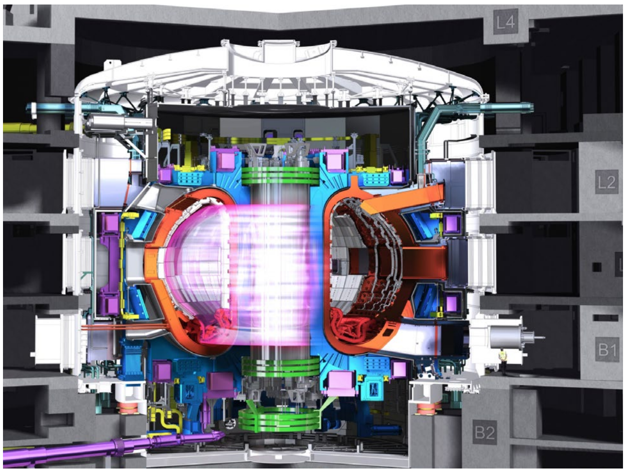

Figure 1: Schematic view of ITER tokamak.

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.

At CSEM, a complete process flow has been developed for the fabrication of bolometers on 20-µm thick YSZ (yttrium-stabilized zirconia) substrates. This includes the temporary bonding of the substrates on carriers, and all the thin film deposition and patterning steps. An example of produced bolometers is shown in Figure 2. The visible side contains all the platinum resistors and contact lines of the sensors. Figure 3 shows a detail of the second side, where gold absorbers are created by electro-deposition. The thickness of these absorbers is 20 µm, i.e. as large as the substrate itself. The role of the Au absorber is to extend the spectral sensitivity of the sensor, and its thickness is a compromise between sensitivity and heat capacity. Stress management is hence very important for ensuring reasonably flat and crack-free devices.

Figure 2: 5-channel bolometer sensor (25 x 22 x 0.02 mm^3).

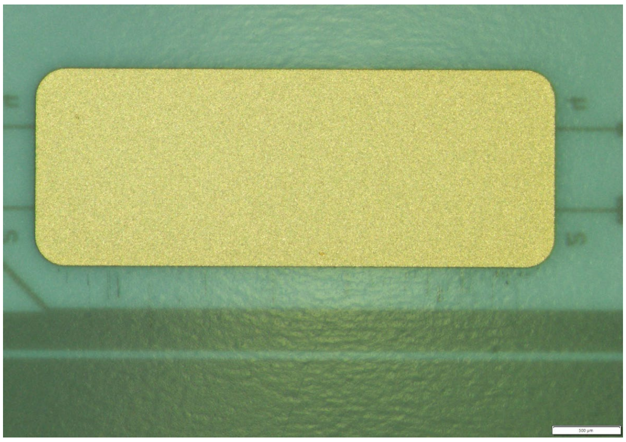

Figure 2: Detail of absorber with electrical contact lines seen through the thin substrate.

The produced devices meet stringent specifications. Specifically, they withstand thermal cycling and exhibit excellent electrical stability. Some sensors have even been trimmed by laser to improve further the equilibrium of the Wheatstone bridge. Resistance variations across a full 5-channel sensor below 0.3% have been reached. The delivered sensors await irradiation testing, which will confirm their suitability for the tokamak environment.

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