VISTA: a thermogravimetry/biosensor system for in-situ analysis of planetary surfaces

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BASIC PRINCIPLES

The instrument here proposed is a thermogravimeter-biosensor system, which aims to measure abundance of volatile compounds and to detect biogenic molecules in any planetary environment.

ThermoGravimetric Analysis (TGA) is a widely used technique to study condensation/sublimation and absorption/desorption processes in the analysed samples [1,2]. The core of the thermogravimeter is a Piezoelectric Crystal Microbalance (PCM), whose oscillation frequency depends on the mass deposited on it: the higher the mass the lower the frequency [3]. The temperature of the device can be changed by means of an appropriate heater, so that desorption/absorption of different volatile compounds is allowed (Fig. 1). The abundance of the released/absorbed volatile compounds is given by the mass variation due to the desorption/adsorption processes, while its composition can be inferred by the desorption temperature.

The MIP (Molecularly Imprinted Polymers) are crosslinked polymers, which are synthesized in the presence of template molecules. The production process uses a target molecule to construct a template of cavities inside the polymer. The cavities so created are then used to trap uniquely (or specifically) the target molecule (Fig. 2). The comparison of this technique with others commonly used in the biological analysis field, shows clear advantages of MIP for space mission thanks to its robustness and for the absence of biological contamination risks of extraterrestrial environments.

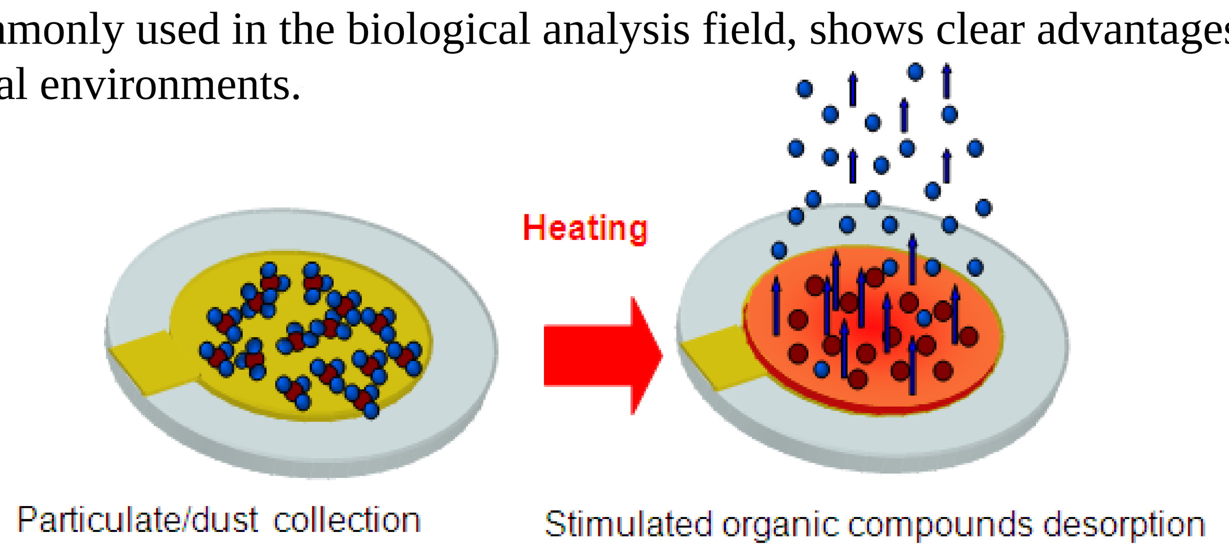

Figure 1. TGA volatile desorption

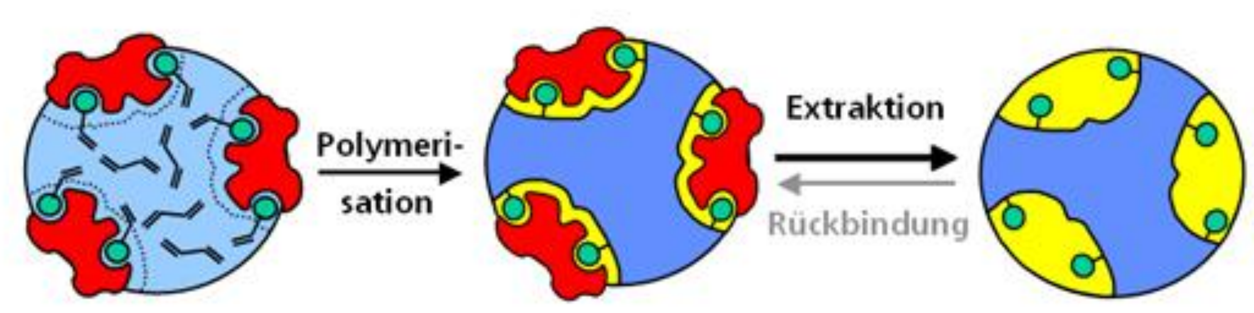

Figure 2. The MIP working principle (courtesy University of Stuttgart)

VISTA CONCEPT

VISTA (Volatile In Situ Thermogravimetry Analyser) is based upon a lab-on-chip miniaturised sensor philosophy, since it has a very small mass/volume and power requirements and it needs a quite small amount of material for the analysis, i.e. less than 1 mg. These characteristics made it an ideal instrument for planetary in-situ missions. VISTA has two different subsystems: S1, the biosensor subsystem, consists in a MIP coupled to a PCM and is devoted to the search of biosignatures, whereas the thermogravimeter subsystem performs μTGA measurements looking for hydrates minerals and organic compounds (Fig. 3) .

The development phase of S1 is at the design level, whereas a laboratory breadboard of S2 is currently operative and under test (TRL 4/5 – see Fig. 4).

The main innovation introduced by VISTA concerns the special design of the thermogravimeter, which is equipped with a built-in heater and a built-in thermistor, which can act as additional heater. This special design dramatically reduces the total mass and the power required to perform thermal cycles.

An upgraded model of S2 is under design, while preliminary evaluation of the overall instrument main characteristics are given in Table 1.

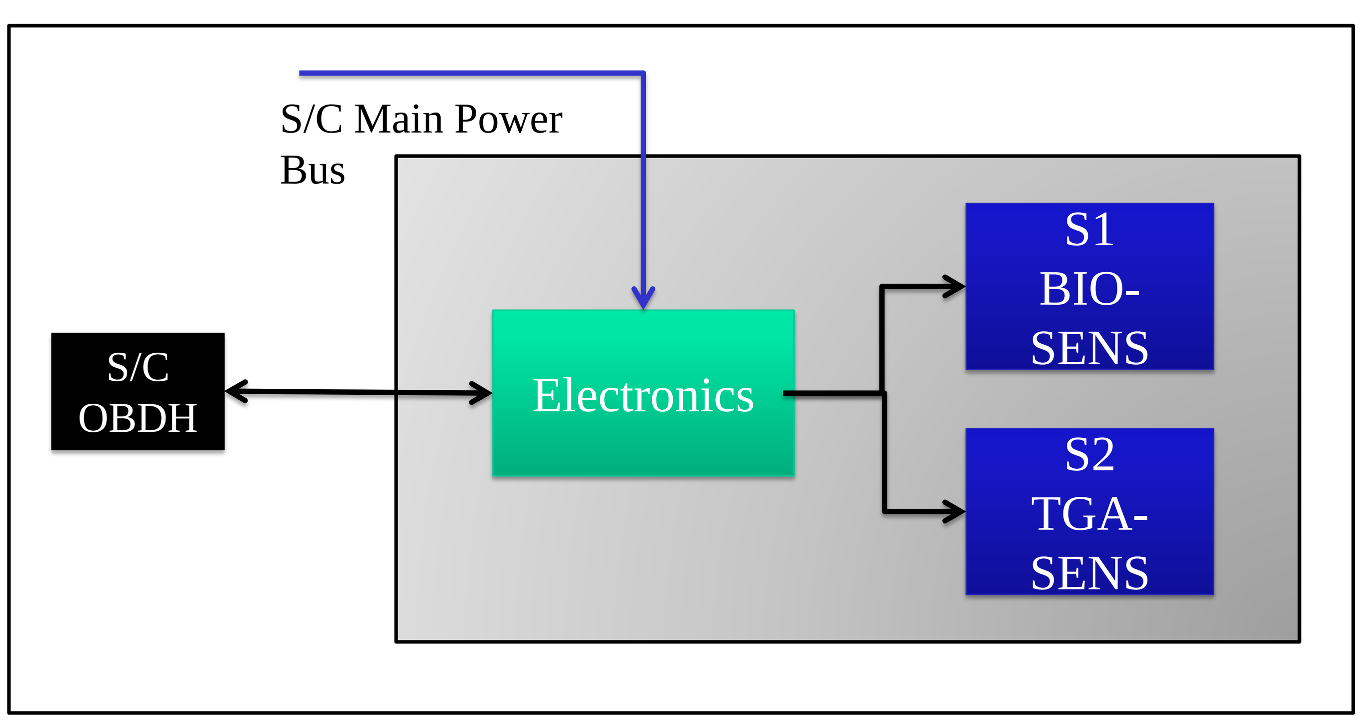

Figure 3. The VISTA block diagram

Parameter	Value/Description
Mass	25 g (one subsystem)
Volume	2 x 2 x 3 cm^3 (one subsystem)
Power (ΔT~500 K)	500 mW in air 50 mW in vacuum
Sensitivities	10 – 100 ppm 0.01 – 1 (ng cm^{-2} s^{-1})
Responsivity	1 ng Hz-1
Detectors Operating Temperature (K)	Subsystem 1: 270 K Subsystem 2: 300 – 750 K
Electronics Operating Temperature (K)	230 – 320 K
Telemetry data rate and volume	256 bit each sampling 1 typical thermal cycle = 1 Mbit

Table 1. Instrumental Characteristics for the Thermogravimetry/Biosensor system. The power needed to increase the sensor from the environmental temperature (ΔT) can be tuned depending onto the chemical species to be studied. The values here reported are evaluated from laboratory measurements at ambient (terrestrial) conditions.

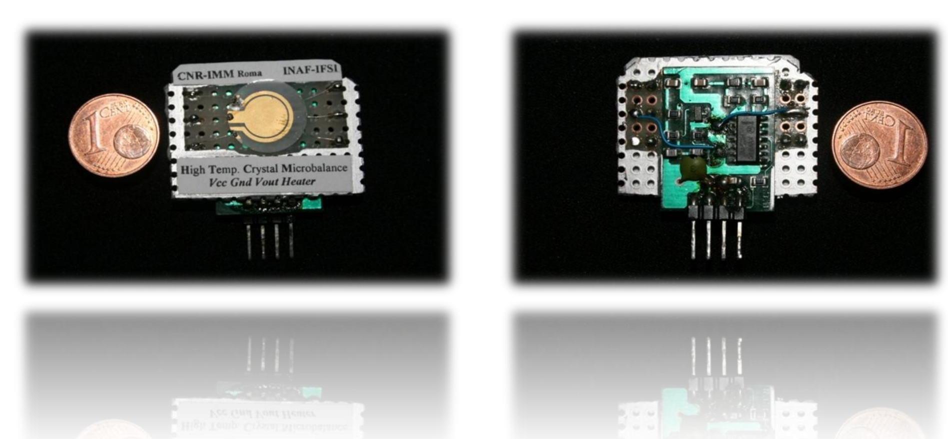

Figure 4. The μTGA Breadboard

FIRST TGA MEASUREMENTS

Preliminary measurements in ambient air show that to increase the sensor temperature of 70 °C from the ambient value (25 °C), reaching a value of 95 °C, the sensor needs less than 0.5 W (Fig. 5). Additional tests in vacuum seem to suggest that a ΔT of 500°C would not require more than 2 W to be performed.

To test the real capability of the device to measure volatile releasing we performed some tests using clay materials. The clay has been firstly hydrated by means of a Controlled Hydration Chamber and then dehydrated by increasing the PCM temperature. We measured that the amount of absorbed and desorbed water are similar (i.e. about 3%) and this demonstrates the capability of our device to perform μTGA measurements. Details of the experiment are shown in [4].

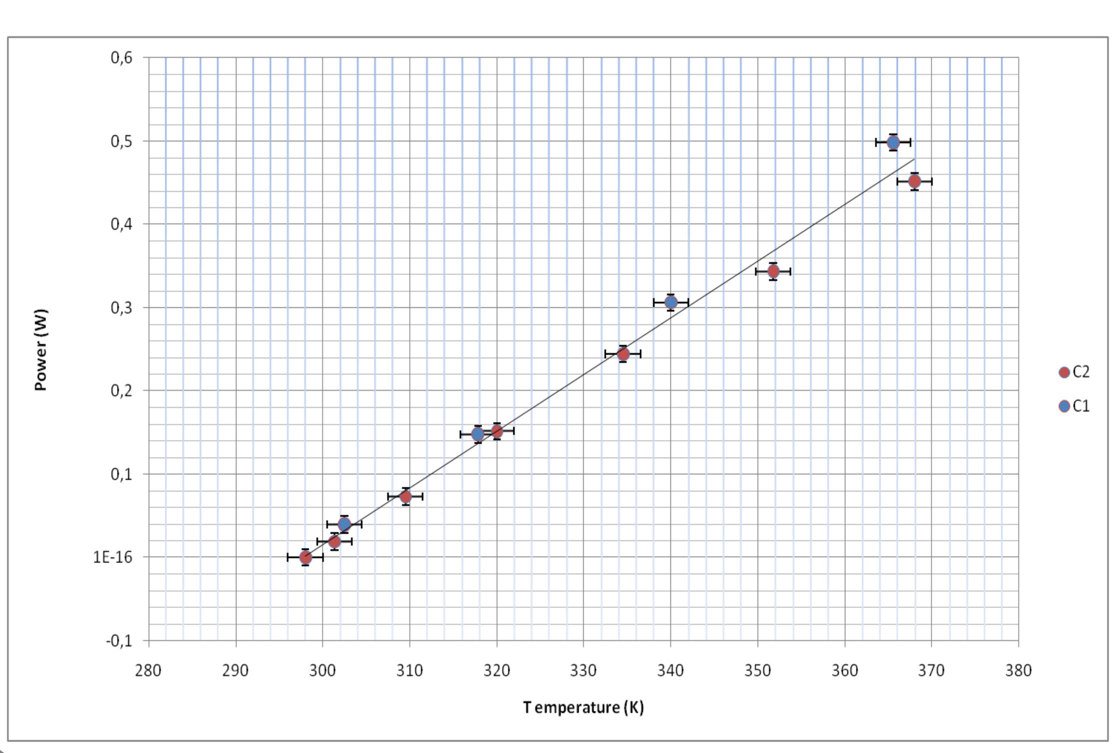

Figure 5. S2 preliminary tests: ΔT vs applied power at room conditions for both C1 (i.e. single heater) and C2 (i.e. double heater) setups

APPLICATIONS

VISTA is under study for the Phase A of the proposed ESA Cosmic Vision mission MarcoPolo-R, addressed to a primitive asteroid, and JUICE. In the second case, it should be coupled with a Penetrator, designed for the surfaces of Europa and Ganimede.

In the MarcoPolo-R scenario, VISTA will have the following scientific purposes:

- *to detect the possible cometary activity of the asteroids*
- *to aid in determining the taxonomy of the asteroid regolith*

The first purpose can be reached setting up the PCM to a low temperature in order to allow the condensation of gases ejected by the possible cometary activity. For the second purpose, the PCM should be heated up to temperatures where organic and water desorptions occur (200-500 °C) [5], so that the measurement of their abundance (related to its taxonomy) would be allowed.

In the JUICE scenario, the aims are to:

- *discern water ice and clathrate hydrates* (which have different sublimation temperatures)
- *infer the composition of non-ice materials on the satellite surfaces*
- *detect the possible presence of organic molecules*

The last two purposes will be likely reached combining thermogravimetry and MIP techniques [6].

VISTA has been also studied for other planetary environments. In a Mars in-situ mission, it would be able to measure the water frost point, the deposition rate of dust and ice, as well as the volatile content in the Martian dust [7]. In the Lunar enviroment, it would measure the ice and volatile abundances. Furthermore, it would be able to measure the electrical properties of the regolith, by attracting charged dust grain by means of a variable electric field, generated locally by the instrument itself [8]. Finally, VISTA can find application also in the study of planetary atmospheres (i.e. Venus and Titan), where it can measure the dew point of condensable species, the abundance of volatile and refractory component of cloud aerosols, the electrical properties of aerosols, as well as the organic content.

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