THE FAMARS INSTRUMENT: AN ATOMIC FORCE MICROSCOPE FOR THE PHOENIX MISSION

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Introduction: An atomic force microscope (AFM), dubbed FAMARS, has been designed for the Phoenix mission to Mars, for determining the size, the distribution, and the shape of dust and soil particles [1-4]. It is part of the MECA (Microscopy, Electrochemistry and Conductivity Analyzer) experiment, and with which it shares the sample delivery system [5].

Design: As for any space mission, volume, weight and power consumption are key design parameters. Moreover, parts and materials must meet shock and vibration, radiation, thermal, and out- or degassing criteria. In addition electrical arcing due to high voltages at the low pressure on Mars is of concern. The AFM consists of an electromagnetic scanner head (see Fig. 1), a micro-fabricated sensor chip (see Fig. 3), and a controller board (see Fig. 4). The total power consumption of the microscope is less than 8.5 W.

Scanner: The x-y-z scanner measures only 12mm × 18mm × 24mm and weights 15g. By using electromagnetic actuation with voice coils instead of the piezoelectric actuation commonly used in laboratory instruments, the scanner can be operated with low voltages, avoiding electrical arcing.

Fig. 1. The electromagnetic scanner head (black anodized) with the micro-fabricated sensor chip mounted in front of it.

The electromagnetic forces have to be counter-balance by mechanical forces in order to generate a smooth, controlled motion of the scanner. An innovative system of leaf-springs made of polyimide, shown in Fig. 2, allowed a good damping of this scan motion, showing moderate temperature dependence over a large range. Moreover, copper leads for connecting the AFM sensor to the controller board could be seamlessly integrated into the springs [6].

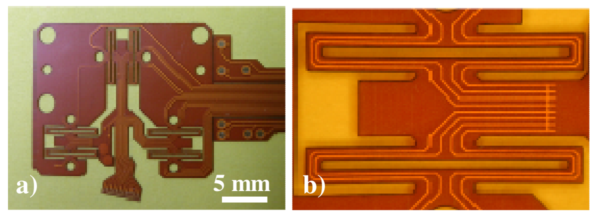

Fig. 2. a) View of the polyimide leaf prior to mounting to the scanner-head. b) Larger view of a leaf-spring with integrated copper leads. The copper lines on the visible side were designed for compensating the bimorph effect. The electrical connections are established by the lines on the hidden side.

Sensor chip: The microfabricated sensor chip consists of eight cantilevers with integrated, piezoresistive deflection sensors. These cantilevers are aligned in a row and mounted on the scanner with two tilt angles relative to the sample. Thus, they can be engaged one after the other to provide redundancy in case of tip or cantilever failure. Silicon tips at the end of the cantilevers are used for probing the sample. Images can be recorded in both, static and dynamic operation mode. In the latter case, excitation of the resonance frequencies of the active cantilever is achieved by vibrating the whole chip by means of a piezoelectric disk.

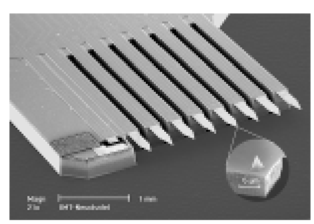

Fig. 3. SEM image of the sensor chip. It consists of eight cantilevers, each ended with a silicon tip.

Controller board: The electronic board measures 300mm × 110mm × 10mm and weights 190g. It is a digital controller which generates the feedback and scanning signals. The on-board processor executes AFM specific, low-level commands and communicates via a serial interface with the Lander computer. The latter downloads the operation software into the RAM of the controller upon power up. It then sequentially requests the execution of the low-level commands, based on predefined, special algorithms for autonomous AFM measurements. Measured images are stored on the Lander computer from where they will be downloaded to Earth.

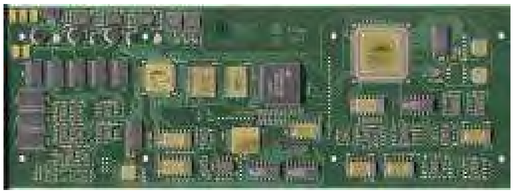

Fig. 4. Image of the electronic controller (300mm × 110mm).

Due to radiation, different damages can be induced by single event upsets (SEU). If a heavy ion hits a register cell, the stored information can be falsified. To secure the data, a triple voting circuit has been implemented, as shown on Fig. 5.a). Each data bit is stored in three independent registers and checked by a voting cell, the output reflecting the majority of the inputs. All important register cells in the programmable logic chips are implemented in this way, which reduces the failure rate by a factor of 1,000 to 10,000.

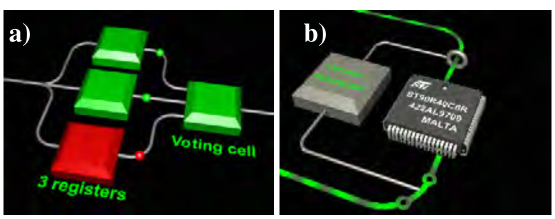

Fig. 5. a) Principle of the SEU protection circuit. b) Principle of the SEL protection circuit.

A more severe hardware failure is a single event latch-up (SEL), which can occur in non-rad hard CMOS chips. If a conducting path is opened between a power line and ground by a sudden ionization due to heavy ion impact, a high current will flow through this path and destroy the CMOS chip by overheating. As not all electronic components on the board are radiation hard, a protection circuit has been implemented to prevent these SEL from harming the electronic components (see Fig.5.b). This module measures the current consumption on all power lines of the card, and immediately shuts down the power if a too high current surge is detected. A short time later, the power is switched on again and the board returns to its normal function [7].

Testing: The properties of the AFM were scrutinized by taking AFM measurements before and after exposure to shocks, vibrations and thermal cycles. Mostly calibration grids were used as samples. Because of the new scanner principle, important parameters to evaluate were the maximal area and the orthogonality of the scanning. Fig. 6 shows a two dimensional calibration grid, which has a pitch of 10µm, imaged by FAMARS. The required scan range of 40µm × 40µm was achieved and the saddle like distortion is in an acceptable range.

Fig. 6. AFM image (dynamic mode, 65µm × 65µm) of a calibration grid in silicon (period = 10 microns).The height information of this top view image is coded in levels of grey. A common plane has been subtracted from the raw data in order to make better use of this grey scale.

Concluding remarks: FAMARS passed the required qualification tests at the instrument level. The flight and the flight spare models were delivered to the Jet Propulsion Laboratory for the integration on the MECA stage and the Phoenix Lander. Thermal vacuum tests are currently in progress on the assembled MECA system. Future work will mainly consist in characterizing the AFM in end-to-end tests and cataloging different samples and Mars-analogues.

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