Demonstration of Micromechanical Cantilevers in Space

Proposal by:
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Summary

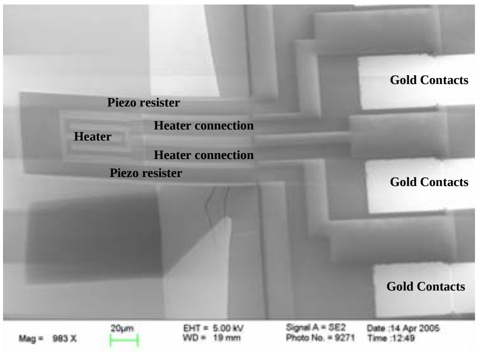
The purpose of the proposed payload is to test and verify the operation of cantilever based sensors in space. This is realized by a comparison of measurements conducted on the satellites exterior and on the interior. The amount of outgassing and the effect of radiation and atomic oxygen on various materials will be the main quantities of interest.
The proposed payload will greatly contribute to raise the Technology Readiness Level (TRL)[i] of especially cantilever based systems but also MEMS components in general.
Even though the system requires considerable time to develop and build, it is of a physical size that could allow it to function as secondary payload.

Background

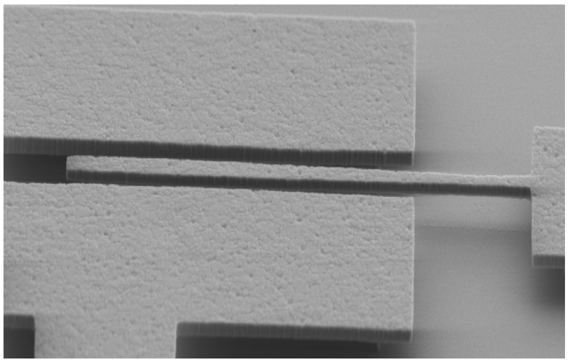
This proposal is derived form a pending PhD application in the area of creating a Nano Environmental Monitoring Unit (NEMU) based on cantilevers for bio/chemical detection. The goal of the NEMU project is to develop a very compact unit that acts as a dust and radiation hazard warning/information system that is deemed necessary in case of all human exploration missions and considered highly valuable in most robotic cases. The unit should be portable and should be easy to add-on to a spacesuit or other relevant equipment. The unit will measure the dust exposure (mass, size and settling rate) from deposition of suspended dust in the atmosphere as well as the general radiation level. The unit has the possibility at a later stage to be upgraded with micro and nanofabricated temperature sensor, pressure sensor and gas detector.
If the proposed payload is accepted it will provide the NEMU project with valuable information especially with respect to suitable cantilever coating material but also regarding mechanical and electrical interfaces.

Cantilevers

Microfabricated cantilevers or beams originate from AFM measurements but are currently being developed for bio/chemical detection of various elements from DNA/protein recognition to gas/explosive detection. The operating principle of cantilever based sensing can be divided into two different areas: Static and dynamic. Where in the static regime the bending of a cantilever resulting from surface stress or temperature change induced by a bio/chemical reaction, is transduced into an electric signal. Figure 1.a shows a micro cantilever with integrated heater (for calorimeter experiments) and piezoresistive elements for detection of the cantilever bending. This cantilever can also be used in the dynamic range but with lower sensitivity due to the larger mass compared to the device shown in Figure 1.b.



(a)



(b)

Figure 1 Picture (a) shows a cantilever for static operation and (b) a 400nm wide cantilever for dynamic mass measurements

The principle utilized in the dynamic area is that the resonant frequency of the resonating cantilever is dependent on the mass of the device. Thus by monitoring the resonant frequency change of the cantilever, a mass change of the device can be detected. By miniaturising the dimensions of the mechanical device, the mass resolution is increased. MIC is currently developing cantilever-based mass sensors with integrated actuation and read-out. These sensors have been seen to have a minimum detectable mass change of approximately 1 ag (10^{-18} g)[ii]. The device shown in Figure 1.b is optimised for this extremely high resolution and utilizes integrated capacitive actuation.

Combining these two methods of detection yields a device capable of detecting chemical reaction along with minute mass changes, which will be the basis of the payload.

Payload idea

The idea is to compare both static and dynamic cantilever measurements on the exterior and interior of the satellite and furthermore compare the measurement of a hermetically sealed device in order to identify the contribution from outgassing. By having individually coated cantilevers (with e.g. composite layers, polymers, biomaterial or carbon nanotubes.) the bending or resonance shift compared to a reference will yield information of the influence of the space environment.

Interaction between UV radiation and oxygen in LEO creates atomic oxygen which rapidly oxidise/etches a number of metals and polymers. The dynamic devices will directly show if a mass change occurs and thereby if the coating is removed due to atomic oxygen exposure. The static systems will provide data revealing a chemical reaction e.g. the braking of bonds in a polymer due to radiation taking place on the surface. The different devices for reference are needed for calibration since especially the temperature will have a direct impact on the measurements.

System overview

The systems will consist of two subsystems where one is placed in direct contact with the space environment and contain two cantilever devices for static and dynamic operation separately. The individual device will have several cantilevers (1-16 depending on available signal lines and driver circuit) each coated specifically which the material to be investigated. Both devices can be placed on the same PCB or

substrate but the device to be operated in the dynamic mode will have to be place on e.g. a piezoelectric element to drive it to resonance.
Ideally there will also be placed a radiation detection reference of e.g. the CdZnTe type which provides excellent spectral resolution[iii]. An identical subsystem will be place inside the satellite with the addition of the hermetically sealed component as shown in Figure 2.

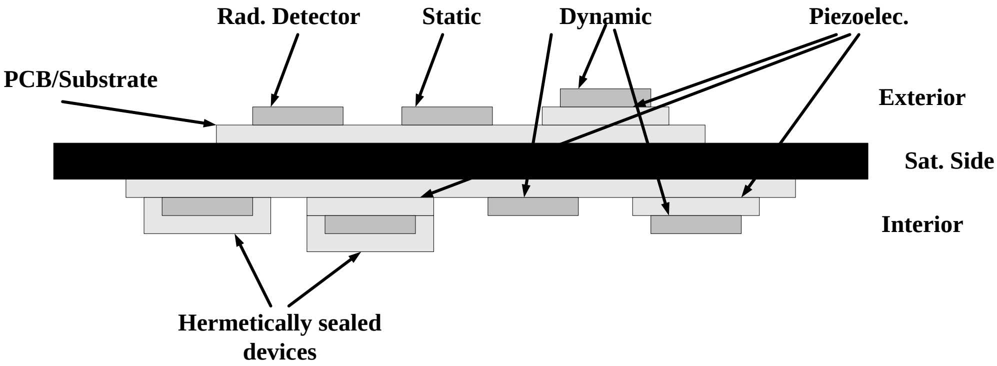


Figure 2 Schematic showing the envisioned system configuration.

Main issues and aspects

Following is listed the main issues and aspects regarding the proposed payload

1. Development time will be close to one year for one person working full time for the sketched ambition level – not including integration.
2. The calibration requires extensive investigation to optimise selective sensitivity so the effect producing the signal is correctly identified.
3. Wireless subsystem communication is a keystone for MEMS devices for space, since interfaces tends to constituted a large amount of the total system mass. Hence a wireless version could be tested, but will raise the development time.
4. Integrated actuation of the dynamic sensor could be considered to reduce the power required for driving the piezoelectric element.

References

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[ii] E Forsén, S G Nilsson, P Carlberg, G Abadal, F Pérez-Murano, J Esteve, J Montserrat, E Figueras, F Campabadal, J Verd, L Montelius, N Barniol and A Boisen, "Fabrication of cantilever based mass sensors integrated with CMOS using direct write laser lithography on resist", Nanotechnology 15 (2004) 628-633.

[iii] I. Kuvvetli, C. Budtz-Jørgensen, *Pixelated CdZnTe Drift Detectors*, Nuclear Science Symposium Conference Record, 2004 IEEE.