INTEGRATION OF MICRO-STRUCTURES, MICRO-TRANSDUCERS AND MICRO-ELECTRONICS INTO MICRO-DEVICES FOR SPACE APPLICATIONS

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ABSTRACT

In the paper we will expose the activities of a typical micro-device company that is now developing several micro-devices for space applications. The focal plane array infrared detector and the smart instrumentation point are made using the full range of micro-structuring, sensing elements and radiation-hard signal-conditioning electronics. On basis of the expertise accumulated during the development of these devices we will discuss the possibilities of integrating micro-structures, micro-transducers and micro-electronics into micro-devices for space applications.

INTRODUCTION

In order to make satellites smaller and less costly, use of novel micro-technologies is essential. In the past 30 years, micro-sensors and micro-actuators (together called micro-transducers), based on silicon technology and associated technologies, have developed rapidly. The last decade two trends can be seen in the world of micro-transducers (more generally designated as micro-devices or even MEMS, micro-electro-mechanical systems).

- On the one hand, some micro-devices become de-electrified, meaning that with the use of a technology originally intended to make electronic components, micro-structures are being developed that have no electrical function at all.
- On the other hand, some micro-devices become smart, meaning that micro-transducers are supplied with extensive electronic capabilities for signal conditioning and communication. The ultimate trend here will be the incorporation of (simple) microprocessors in the micro-device.

For space applications, an integration or at least hybridization of these two trends will take place, in which sensors become smart by integrating electronics, and may incorporate mechanical structures for mechanical, optical or other non-electronic functions.

At Xensor Integration, these trends are also visible in the work carried out for space applications. At present, two space micro-devices are being manufactured, the one an infrared radiation detector focal plane array (FPA) using silicon technology and micro-structuring (Ref. 1), the other a smart instrumentation point (SIP) incorporating (radiation hard) sensors and signal conditioning electronics designed for space (Ref. 2).
Other (non-space) activities at Xensor Integration include micro-structures without any electronic sensing or signal conditioning function (the pure mechanical structures), and also magnetic sensors for magnetic-field vector determination and flow sensors for air-flow vector determination. Nano-calorimeters that can be used for field experiments with live bacteria are also an expertise of Xensor Integration, and could be used for biological experiments in space.

2. PRESENT MICRO-DEVICES FOR SPACE BY XI

2.1 Focal Plane Array Infrared detector (FPA)

Two types of optical sensors are mainly used for the accurate stabilization of the platform of an Earth-orbiting satellite with respect to the Earth: Star Tracker and Earth Sensor. The Star Tracker is a CCD camera which images a star pattern and very accurately determines the orientation of the satellite in a Galilean reference coordinate system. The Earth Sensor is a thermal device that determines the edges of the infrared Earth in the 14-16 μm wavelength band, and by doing this keeps the Sensor (and thus the platform) exactly oriented towards the Earth (centered or biased) with respect to the orbital reference coordinate system. The Earth Sensor is generally less accurate than a Star Tracker, but more tolerant to space radiation and also much less costly. So, up to now, it is very widely used for various types of ACS, mainly for geo-stationary platforms where the required lifetime is the longest.

Sodern in France (a subsidiary of Aerospatiale-Matra) is a renowned manufacturer of both Star Trackers and Earth Sensors. Present models of Earth Sensors are based on a single element infrared detector, which scans the Earth and the Space thanks to a rotating mirror. Sodern wanted to develop a new generation of Earth Sensors without moving parts, which are therefore more compact, smaller, lighter and more economic. The heart of this Earth Sensor is a novel infrared detector array that Xensor Integration has developed for Sodern.

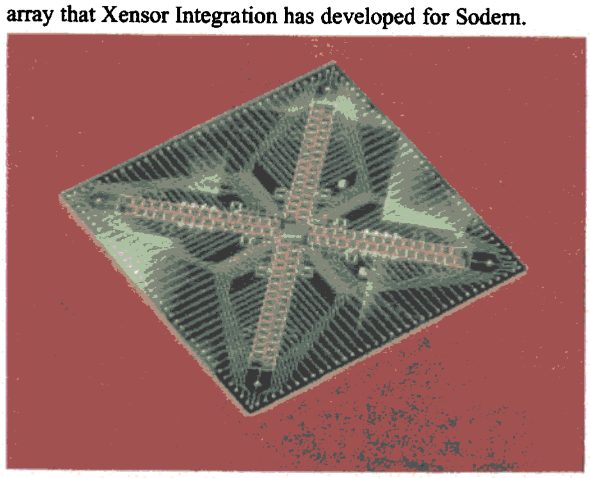

Figure 1: Photograph of a Focal Plane Array silicon infrared detector chip (size 20.5x 20.5 mm) that consists of four arrays of 32 pixels each.

Photograph: Xensor Integration (Ton Schapers)

For the geo-stationary orbit (STS02 Sensor), the detector chip, which measures 20.5×20.5 mm, comprises a cross of four staggered arrays of 2×16 pixels, each array about 10 mm long with the arrays on the diagonal of the chip to decrease the chip size, see Fig. 1. This small detector chip enables Sodern to decrease the size of the optics and mechanics of the entire instrument, thus reducing weight and size, an important objective of the development of the new generation of Earth Sensors. By using bipolar silicon technology in conjunction with advanced electro-chemically controlled micro-machining and silicon thin-film technology, we realized a Focal Plane Array infrared detector which fulfilled all the requirements necessary to obtain the new generation Earth Sensor. This chip is hybridized with CMOS radiation hard multiplexers (see Fig. 2) and packaged to facilitate assembly in the Earth Sensor.

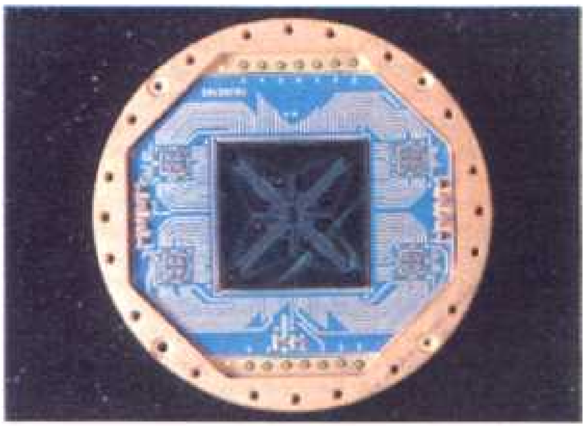

Figure 2: The FPA detector chip mounted in a ceramic hybrid with radiation resistant multiplexers inside a metal suspension ring.

Photograph: Sodern

Pre-qualification tests have been successfully performed and production up to space level quality assurance will commence in the next few months, which will be used for commercial satellites. The detector features a pixel sensitivity of about 60 V/W for a 495×440 μm active area, at about 23 kΩ electrical resistance and less than 16 ms time constant. Using this detector chip, Sodern has been able to obtain a reduction in the new Earth Sensor, of 2-3 fold in size, weight (from 3.5 to 1.1 kg) and power consumption (from 7.5 to 3.5 W), compared to the previous Earth Sensor using a rotating mirror (Ref. 1).

2.2 Smart Instrumentation Point (SIP)

With the increasing complexity of electronics in satellites, and also the ever-present wish for sensory input and thus for on-board sensors, efficient electronic communication in the satellite becomes more and more important. Electronic buses on which all sensors and instruments can put their data for or be interrogated by the central micro-controller are the solution for this. In collaboration with ESTEC/ESA Xensor Integration has designed what is called a 'Smart Instrumentation Point' (SIP). The purpose of this SIP is to provide a data-acquisition chip that will interface sensor devices with the satellite's bus. The chip, manufactured in bipolar technology, is radiation hardened, and will survive more than 100 kRad, see Fig. 3. A unique feature is the on-chip radiation dose meter, which functions regardless whether the chip is powered or not. So, the chip can register how far the deterioration of nearby components due to radiation has progressed, and thus can act as a health-monitoring sensor. In addition, is has a temperature sensor for general purposes operating between -40°C and +125°C.

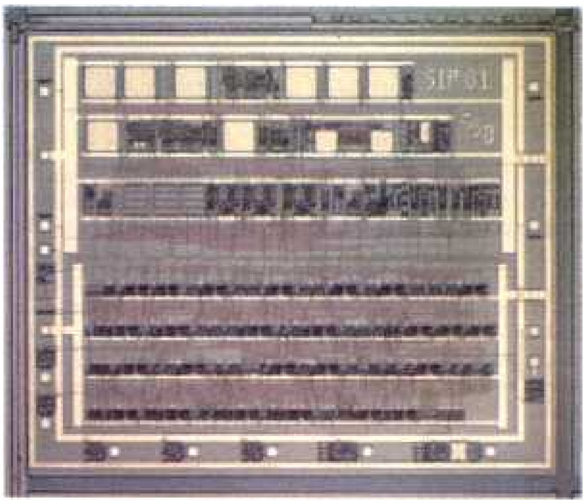

Figure 3: Smart Instrumentation Point for satellites, including temperature and radiation-dose sensor, amplifiers, A-D converter and 2-wire bus.

Photograph: Xensor Integration

The data acquisition part of the chip consists of a multiplexer, followed by a programmable-gain amplifier with offset compensation. Digitalization is carried out by a 14-bit sigma-delta A-to-D converter. The chip has a two-wire serial interface bus running at 100 kHz, and each SIP has a unique 5-bit address that is set internally. The chip is packaged in a metal housing 2 cm long, and total 0.6 cm^3 with 8 wires, 3 for the bus, 2 for the power supply and 3 for analog purposes, see Fig. 4 (Refs. 2, 3).

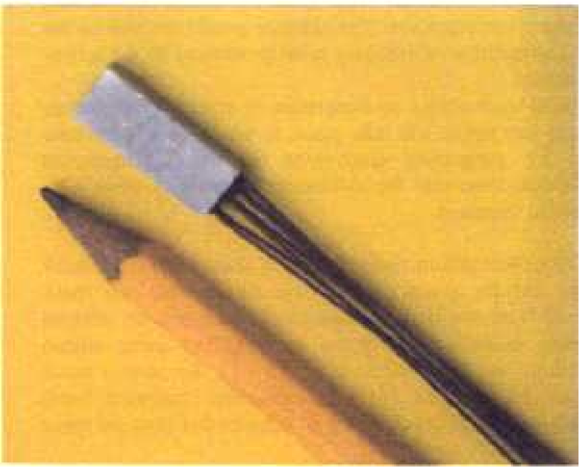

Figure 4: The Smart Instrumentation Point for space applications packaged in a special metal housing, with eight wires for power supply, digital bus and analog connections.

Photograph: Xensor Integration

3. POSSIBLE NEW SPACE-ORIENTED DEVICES

3.1 3-D compass based on smart Hall sensors

A major problem for realizing a 3-D compass with silicon magnetic sensors is the offset, and more important, the offset drift of these sensors. The Hall sensors is one of the best behaving magnetic sensors, but Earth's magnetic field of some tens of μT is usually much smaller than the offset and offset drift of a conventional Hall plate. Recently, new devices consisting of multiple Hall plates with an offset reducing geometry have been developed, and also Hall plates have been developed which are measured (sequentially) in different modes so as to reduce the offset. At Delft University, research has been carried out for about ten years now to develop a Hall plate with minimal offset and offset drift. In this so-called spinning-current Hall plate 8 contacts are made to the active layer, see the left top of Fig. 5. By biasing the Hall plate consecutively from each of these 8 contacts, offset (and therefore offset drift) could be reduced to a level of the order of a few μT, well below the value of Earth's magnetic field vector (Ref. 4). In the chip shown in Fig. 5, the electronics needed to 'spin' the bias current around the eight contacts of the Hall plate (hence 'spinning-current' Hall plate) is integrated along with the Hall plate itself.

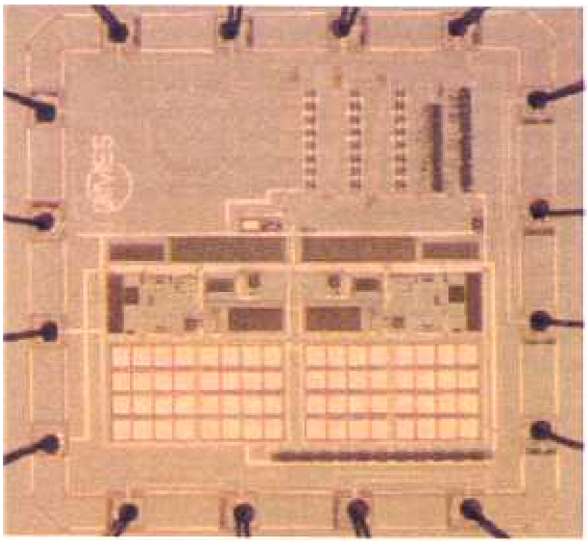

Figure 5: Spinning-current Hall-sensor with eight current contacts (left top) with offset correction and analog electronics (bottom) on the chip.

Photograph: Xensor Integration

Using two or three chips in an orthogonal set-up, it is possible to measure the magnetic field vector in a plane (such as the surface of the Earth) or in space. Figure 6 shows a set-up with two chips perpendicular for compass applications. For this a special lead frame has been designed on which the chips are die-bonded and wire-bonded, after which the chips are set-up in a position at exactly 90° with respect to each other. After this the entire assembly is molded using epoxy. For space applications, a radiation-hardened chip may be designed, and an assembly of three chips measuring the three components (*x, y, z*) of the magnetic field can be used to measure the direction and strength of the field. This may be interesting for the determination of magnetic phenomena around Earth, the sun and other celestial bodies.

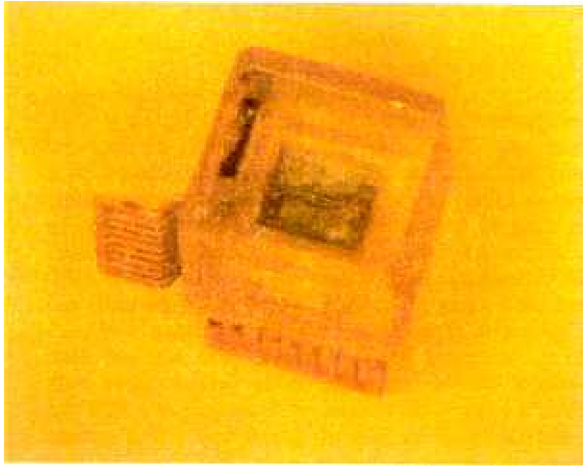

Figure 6: Two spinning-current Hall sensor chips, packaged perpendicular to each other to determine the magnetic field vector on the surface of the Earth.

Photograph: Xensor Integration

3.2 Nano-calorimeters for biological experiments in space

For diverse applications, nano-calorimeters are being used consisting of small silicon chips that can measure the heat created by biological or chemical phenomena (Ref. 5). For such experiments, micro-total analysis systems (μTAS) are being developed, incorporating channels, driving mechanisms (such as electrostatic forces being exerted on ions in solutions) and sensors.

The nano-calorimeter can detects heat with a resolution of about 10-50 nW. This opens up the way to measure, for instance, the metabolism of bacteria, which is typically of the order of 100 pW per bacteria. With a set of 1000 bacteria, analysis of their metabolism can be carried out when they are subjected to nutrients (glucose) or toxic substances (pharmaceuticals). Chip technology enables us to make many nano-calorimeters on a single silicon chip, allowing parallel analysis. Figure 7 shows a chip with four nano-calorimeters in one housing, the total size of the chip being 10x10 mm. Also enzymatic or other chemical reactions can be thermally monitored in this way. Since the nano-calorimeter basically consists of a micro-machined membrane with a thermopile on top of it, it is very well suited for application in space, since the thermopile can be made very radiation resistant.

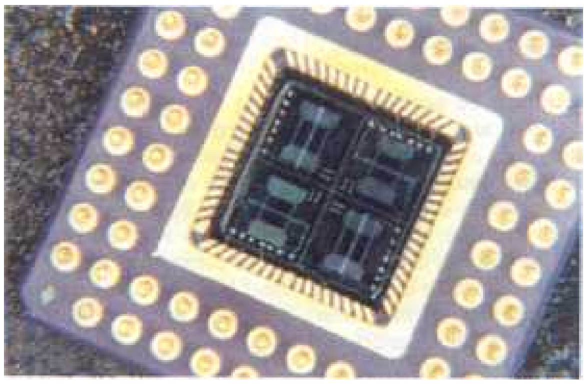

Figure 7: Four nano-calorimeters in a single pin-grid-array housing.

Photograph: Xensor Integration (Ton Schapers)

4. FUTURE MICRO-SYSTEMS FOR SPACE

4.1 Systems for experiments with fluids

For (bio)-chemical experiments in space, so-called micro-total analysis systems are being developed. These integrate sensors, actuators and channels to arrive at a miniature chemical analysis system that can be more or less self-contained. Such systems are often made of silicon and glass components. Other layers made of, for instance, PCB-epoxy boards can also be used. Figure 8 shows a HPLC component (High-Pressure Liquid Chromatography), in this case an ordinary restriction. By making a sandwich of glass, silicon (with channels) and glass (also with channels), a hydraulic resistance is created, which can withstand liquid pressures up to 300 bar. Such components can be assembled using ground plates with channels to connect the component flows, just as a PCB can assemble electronic components. In this way, µTAS systems are being developed at this moment, which can be very interesting for biological and chemical experiments in space.

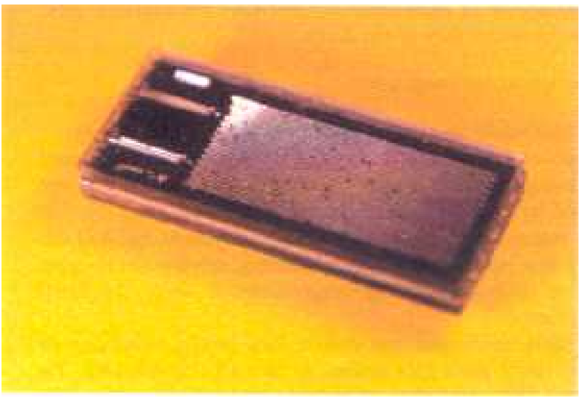

Figure 8: A 300-bar HPLC component for creating a hydraulic resistance. The component is made of a glass-silicon-glass sandwich structure, with the silicon and top glass layer structured to create the required channels.

Photograph: Xensor Integration

4.2 Combining smart sensors and mechanical systems

Using Smart Instrumentation Points as described above, and radiation-hardened micro-controllers, smart micro-systems can be made which incorporate sensors and actuators. These systems are then capable of carrying out chemical analyses, processing the data and sending the over a bus to the central micro-controller of the satellite.

Or they may be capable of measuring the magnetic field vector down to a resolution of 1 µT, and also sending the resulting *x,y,z* components to the central micro. Combination of the Smart Instrumentation Point and the spinning-current Hall sensor on a single chip is no problem from processing point of view. By using a BiCMOS process both the Hall sensor, the switches used for spinning the current, and the SIP can be manufactured on a single, smart Hall chip. Making a set-up with three of such smart Hall chips and combining these with a small micro-controller, results in a smart magnetic 3-D compass.

5. CONCLUSIONS

A lot of progress is being made with sensors, actuators and even micro-systems useable for space. Reliability and radiation hardness are important requirements for these components. Many sensors and actuators are inherently radiation hard, or very insensitive to radiation. Electronics technology is also making progress in terms of radiation hardness, which means that combining sensors, actuators and electronics is also becoming more reliable for space applications. Thus. Micro-Electro-Mechanical Systems, MEMS in short, are becoming more and more an option for use in micro- and nano-satellites. These MEMS will include sensing, data processing, actuating and even digital communication possibilities in small volumes, sometimes not much larger than a silicon chip. This in turn facilitates the construction of micro- and nano-satellites.

6. REFERENCES

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