# Two Axis MOEMS Sun-Sensor and Electron Emitter developed for DTUsat.

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## Abstract

*The student build Cube-Sat DTUsat measures 10 cm on the side and weighs only 1 kg. With more than 10 sub-systems miniaturization is mandatory and MEMS is an obvious choice for sub-system down scaling. Here we present the two MEMS based sub-systems for DTUsat a sun sensor and an electron emitter. The sun sensor measures 7x39x50 mm$^3$ and weighs 10 grams including electronics in the present design. From our measurements we estimate a resolution of 3º, with a field of view of +/- 70º. The electron emitter measures 10x20 mm$^2$ and has 1,6 millions emitting tips. Each tip sits in the centre of a squared well measuring 6 μm on the side. The emitter is designed to be operated at 90-120 V.*

## Introduction

MEMS devices possess a number of features advantageous for space applications; e.g. low weight, high mechanical accuracy and robustness. At MIC two Space-MEMS devices has been developed. A MOEMS sun sensor and an electron emitter. Both devices were intended to fly on DTUsat.
DTUsat is a student build pico satellite. Its overall dimension is 10x10x10 cm$^3$, it has a total weight of 1 kg. The payload on DTUsat is an electro dynamic tether. A current running in the tether will interact with the earth's magnetic field and exert a force on the satellite. Depending on the direction of the current and the orientation of the tether the force will either accelerate or decelerate the satellite. On DTUsat the tether experiment aims at decelerating the satellite, thus causing the satellite to de-orbit. DTUsat was launched June 30. 2003. Unfortunately only the sun sensor was completed before the deadline of DTUsat subsystems.

## The MOEMS Sun-Sensor

The sensor is a slit type sun sensor with triangular photodiodes [1].
It is build up by two major parts namely the photo diodes and a lid. The photo diodes are fabricated on a SOI type silicon wafer. The lid covering the diode has a well-defined optical slit made with a thin film gold layer. The sensor measures 7x8 mm$^2$.

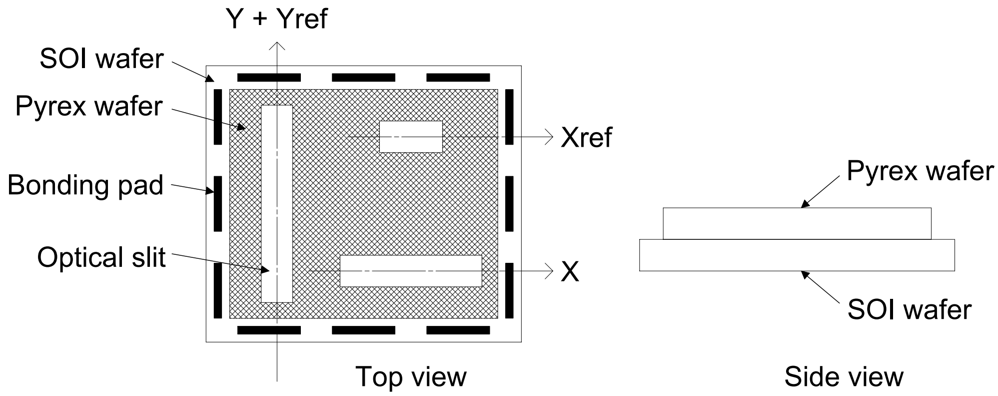


Figure 1. Shows a schematic view of the sun sensor. Each chip contains two sensors placed perpendicular to each other.

The sensor chip is glued directly onto the PCB containing OP-Amp's and AD-converter. The electrical contact between the sensor chip and the PCB is established with direct wire bonding. Since the sun sensor may experience thermal cycling the wire bonding wires are not encapsulated instead a palisade protects them. The palisade is created by 8 pieces of component leads, which are soldered into the bottom side of the PCB and stretches out on the topside. The PCB with sun sensor measures 7x39x50 $mm^3$ and weighs 10 grams.

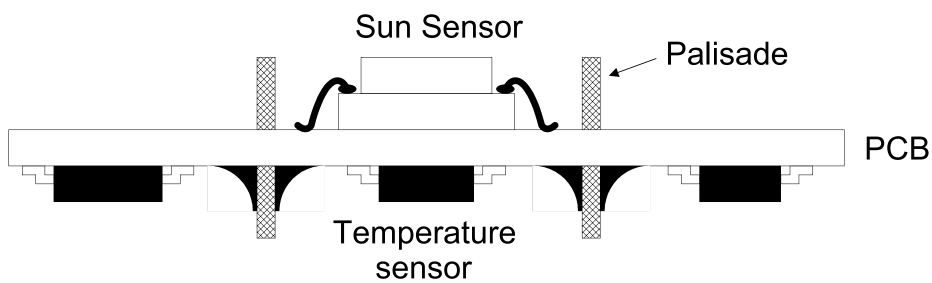


Figure 2. Shows a schematic view of the sun sensor mounted on the PCB. A palisade surrounding the sensor protects the wire bonds.

**Fabrication**

The sensor and lid is fabricated by a total number of 43 process steps and 7 masks. A brief description giving only the main steps of the fabrication is presented in the text and figures 3a, 3b and 3c below.

The SOI-wafer:

1. A protective thermal oxide layer is grown on the wafer
2. Mask number one defines the n-type implantation
3. Mask number two defines the p-type implantation
4. A silicon dioxide layer is grown on the wafer. The oxide growth both creates an anti-reflective layer and activates the implanted ions.
5. Contact holes through the oxide is defined by the third mask
6. The fourth mask defines the electrical leads
7. The fifth and last of the SOI wafers masks defines the etch pattern for the RIE-step. The individual chips are electrically separated by the RIE.

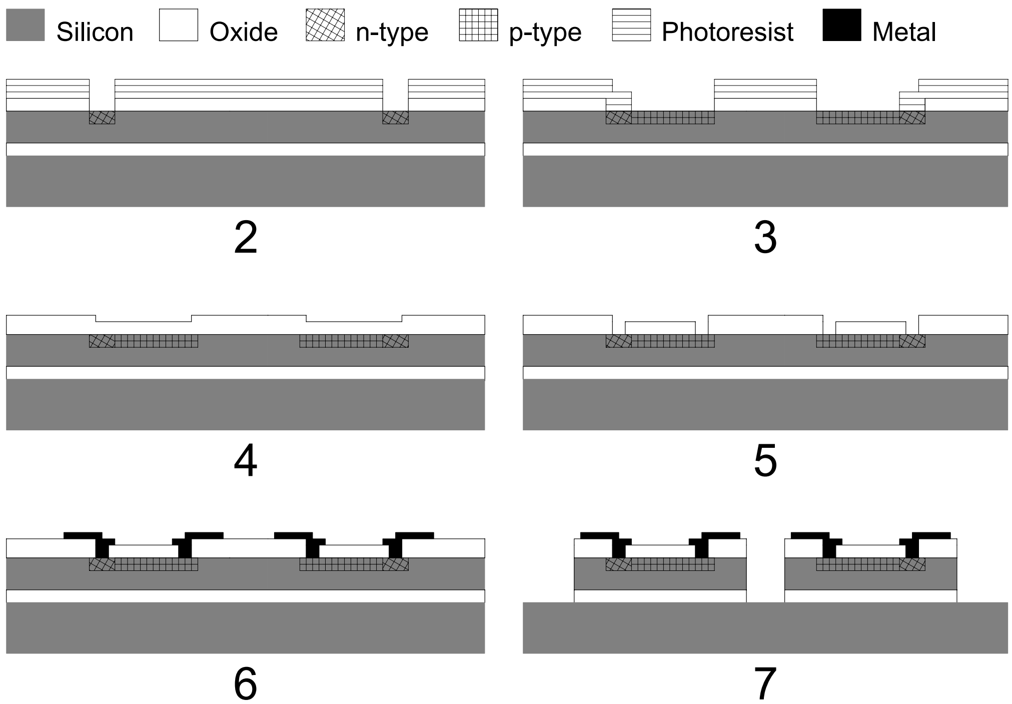


Figure 3a. Shows the main process steps on the SOI wafer from step 2 to step 7 as described in the list above.

The Pyrex wafer:

8. Mask number six defines the footprint of the Pyrex wafer such that it fits into the structured surface of the SOI-wafer.
9. The optical slits are defined with mask number seven in a lift-off step.

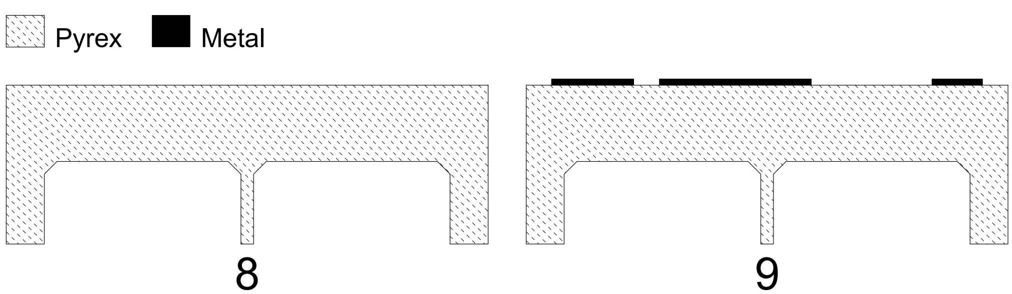


Figure 3b. Shows the main process steps on the Pyrex wafer as described in the list above.

Both wafers:

10. The two wafers are assembled and bonded together.
11. After bonding the wafer is diced up in individual sun sensor chips ready for testing.

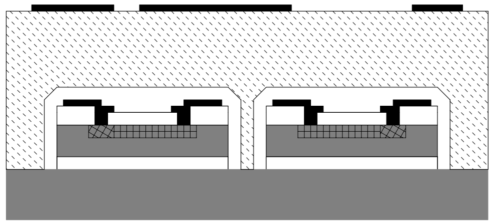

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Figure 3c. Shows the assembled wafer pair prior to dicing. The drawing only shows on sensor and is not to scale.

**Electronics**

The signals from each photo diode is feed to the PCB individually, though not necessary this is done in order to keep the design as versatile as possible. The differential current between the two major photodiodes is amplified by an op-amp. The reference signal is also amplified by an op-amp. The amplified signals are then feed into an AD-converter. The differential signal is feed into the input of the AD-converter and the reference signal is feed into the reference of the AD-converter. By feeding the reference signal to the reference pin of the AD-converter we obtain a division of the differential signal with the reference signal. This division cancels out unwanted parameters such as aging and temperature dependence.

**Measurement results**

The sun sensors has been tested and calibrated on an optical table with a collimated Xenon lamp light source. The sensor was placed on a turntable with an angular resolution better than 0.01º. The graph below shows a typical measurement. It is seen that the sensor output is not completely linear and that some parts of the graph is not single valued. The reason for this is not yet fully understood, but may be explained by internal reflections in the Pyrex glass or residues from the dicing deposited on the sensing areas. From the graph below we estimate a resolution of the sensor of 3º.

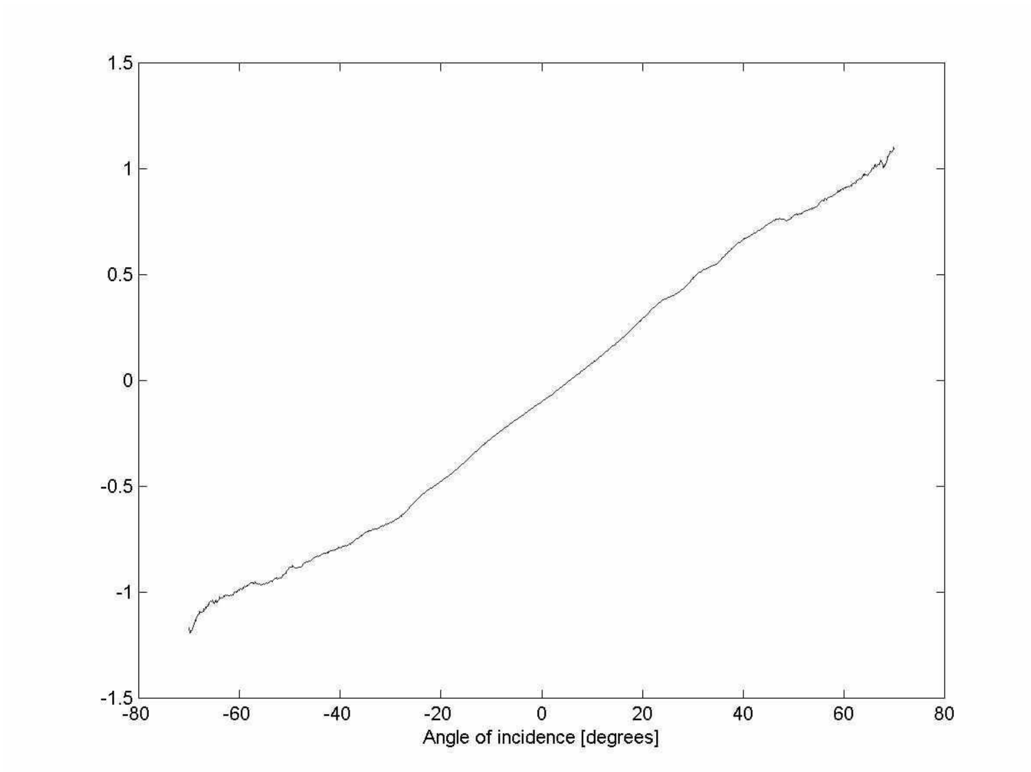


Figure 4. A typical characteristic of a sun sensor. As can be seen the graph is not linear and not single valued in all points. From the graph above a resolution of 3º has been estimated.

## The Electron Emitter

The electron emitter for DTUsat is a field emitter array fabricated on a SOI-like wafer structure using one mask step. The field emitter consists of a sharp tip placed in a well surrounded by a gate. When a sufficiently high voltage is applied across the tip and the gate, electrons are emitted from the tip. The emitting efficiency is dependant on the tip material, the tip shape and the applied field. Molybdenum Silicide ($MoSi_2$) was chosen as tip material due to its high oxygen resistance combined with a relatively low work function.

The tip is shaped by an isotropic etch followed by an oxidation step and oxide etch. This process sequence was previously developed at MIC for AFM tip fabrication [2,3].

By reducing dimensions high field strength can be obtained at low voltages. In this design the wells are squared and has a side-length of 6 μm. Figure 5 below shows a schematic of the emitter design.

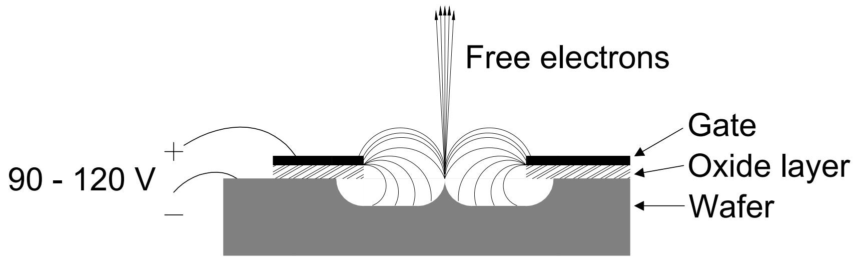


Figure 5. Shows a schematic view the electron emitter for DTUsat. The emitter works as a field emitter, it consists of a sharp tip placed in a well and surrounded by a gate layer. When a sufficiently high voltage is applied between the tip and the gate electrons are emitted from the tip.

The emitter has been designed to withstand a tip to gate voltage of 200 V. The intended operating voltage is in the range of 90 – 120 V. One chip measures 10 x 20 mm and contains roughly 1,6 million tips. Each chip is divided up into 5 individually addressable sub emitters. Since all tips on one chip are electrically connected the addressing is done by applying a voltage to the gate area. Figure 6 below shows the layout of the gate areas.

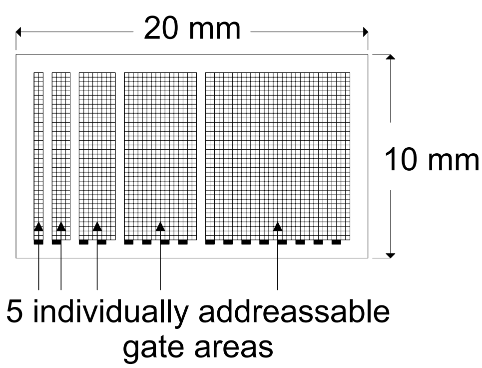


Figure 6. Shows the layout of one emitter chip. Two adjacent areas scales with a factor of 2 it is thus possible to vary the number of emitting tips from ca. 50.000 to 1,6 million is steps of 50.000.

**Results**

No emitter has been tested since they all short-circuited; this also means that no emitter was mounted on DTUsat. Figure 7 shows a SEM micrograph of an area of one of the electrons emitters. The short-circuiting is probably caused by etch mask residues from the isotropic etch. Such a residue is visible on figure 7 lying in the last well to the right second row from the bottom. The residue leans on the sidewall.

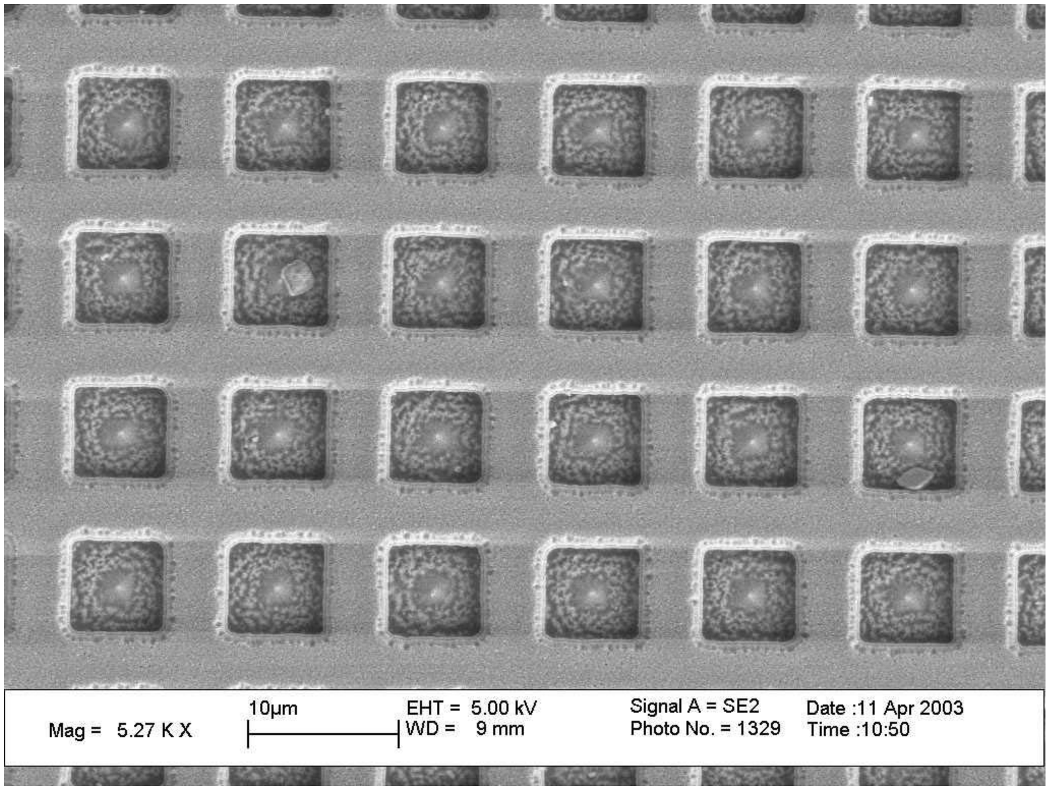


Figure 7. A SEM micrograph of an emitter area. The squares (wells) are 6 μm on the side; in the centre of each well the tip is visible. The last well to the right second row from the bottom has an etch mask residues from the isotropic etch lying in the well leaning on the sidewall. This residue and other similar pieces is probably the reason for the short-circuiting of all the emitters.

## Future work

After the completion of DTUsat we have now started a new project. A MEMS based ion-propulsion system for space applications. The general idea is to accelerate ions from a plasma with an applied field. Figure 8 shows a schematic of the system.

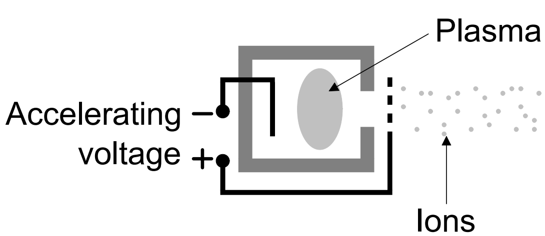


Figure 8. A schematic of the MEMS based ion propulsion system. Ions are accelerated from plasma by an applied field.

## Conclusion

The MEMS in Space group at MIC has now completed two MEMS projects for DTUsat. The sun sensor was completed, tested and mounted on DTUsat. The sensor has a total weight of 10 grams, including PCB, and measures 7x39x50 $mm^3$. With an estimated resolution of 3º the sun sensor did not quite match the initial specifications of 1-2º. If DTUsat-2 is to be realised with sun sensors the specifications will be enhanced. The process sequences for the electron emitter needs some further development in order to obtain functioning emitters, however it is believed that the present problems can be solved.

A MEMS based attitude system combined with a MEMS based propulsion system brings the All-MEMS Autonomous Satellite closer.

## References


[1] Jan H. Hales and Martin Pedersen, Two-Axis MOEMS Sun Sensor for Pico Satellites, proceedings Small Satellite 2002, Aug. 12-15, Utah State University, Logan, Utah

[2] A. Boisen et al., AFM probes with directly fabricated tips, J. Micromech. Microeng. 6 p. 58-62, 1996

[3] A. Boisen et al., Indirect tip fabrication for scanning probe microscopy, Microelectronic Engineering. 30 p. 579-582, 1996