WOV – Working On Venus
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Venus has fascinated mankind since ancient times, due to its proximity to earth. It is also both similar to and different from earth, in terms of size and atmosphere, respectively. Although many things can be measured from afar, some important properties of interest need to be investigated with an orbiter or lander equipped with dedicated scientific instrumentation and supporting electronic systems. The surface temperature of 460 °C, along with atmospheric pressures of around 92 bar (an atmosphere consisting mainly of CO_2), precludes any manned missions. Although the Soviet Union managed to land several Venera probes in the seventies, the electronic system made of silicon only lasted a few hours before becoming too hot. Very few images exist of the surface, due to the atmospheric cloud cover. There are many issues regarding the seismic activity, atmospheric composition and even discussions regarding the possibilities of present or previous life, which would require long-term monitoring and imaging.

Our approach

Other semiconductors than silicon can operate at temperatures around 460 °C: silicon carbide (SiC) and gallium nitride (GaN) are two prime candidates in this proposal. KTH has over 20 years of experience in research with SiC devices and integrated circuits, demonstrating high voltage devices (spun off in TranSiC AB and later acquired by Fairchild Semiconductor) and digital integrated circuit operation at 500 °C. Radiation hardness has also been demonstrated for SiC devices. Linköping University likewise has 20 years' experience of high-temperature SiC gas sensors, spun off in SenSiC AB. We now see an opportunity to demonstrate an entire system. This would include sensors, amplifiers, data conversion and storage, radio interface and power supply, which would make a Venus lander feasible. At the start of the project, negotiations will be initiated to collaborate with international organizations on a launch. As our system requires no bulky or heavy cooling system, one or more landers could easily be included in the payload. Adjunct Professor and former Astronaut Christer Fuglesang has been included in the project group, as a liaison to start these discussions, and collect requirements and suggestions from industry and the Swedish National Space Board. Our vision in the related HOTSiC project applies also to WOV: "to boldly go where no electronics has gone before". The infrastructure required for this project is already available at the MyFab KTH Electrum Laboratory, where important parts of the instrumentation have been previously acquired with support from the Knut and Alice Wallenberg Foundation.

Uniqueness in an international perspective

Venus research is ongoing, and several explorations are ongoing or have been proposed, some of them based on orbiters at high or low levels (satellites and balloons), or even landers with silicon electronics planned to last a short time (Venera-D 2016 and VITaL 2021). Our proposed high-temperature electronics (SiC or GaN) and sensing system could very well complement these, but would offer the extended data collection time needed to enable, for instance, seismology. NASA has long-term goals of further exploring Venus in situ, but most of the proposed solutions involve cooling systems for the electronics.

There will surely be terrestrial spinoffs from aiming at this high-temperature technology. NASA has an extensive webpage documenting the spinoffs of the Apollo and Space Shuttle program. Prime areas for high-temperature electronics are nuclear energy safety, geothermal energy, oil and gas drilling. The Apollo program was one of the first large users of integrated circuits and probably gave the whole industry a large boost, as well as a Nobel Prize in Physics for Jack S. Kilby in 2000.

Major achievements

The project started January 2014 and has eight PhD students in the different work packages. Our present bipolar technology has been scaled to smaller transistors, and self-aligned nickel contacts have been developed. Four new integrated circuit designs were made for different parts of the lander electronics: CMOS circuit test set, a 4-bit microprocessor, RF transistors for the radio transceiver and a prototype pixel sensor for the imaging. Most of these have been fabricated by the PhD students in the KTH Myfab clean room, some are still in progress. Preliminary testing and modeling show operation up to 550 °C, sufficient for the Venus target. A first demonstration has been made of capacitive inertial sensing at high temperatures; gas sensors have been annealed at 500 °C for 300 h; photodiodes sensitive in the near UV range (200 to 400 nm) have been tested up to 550 °C. Power sources have been identified, and passive components like inductors have been tested to 500 °C. A reference group has been formed. Preliminary contacts have been made with NASA Glenn and NASA Ames for later testing, and a proposal is being drafted for ESA. A presentation titled “Electronics on Venus – Why?” was made aimed at high school students, and this was recorded by Swedish Television for Kunskapskanalen (UR).

Links: www.workingonvenus.se
www.youtube.com/watch?v=lPRyoMSB4IA

Ten selected publications from members of the project group

1. L. Lanni et.al., “500 °C Bipolar Integrated OR/NOR Gate in 4H-SiC,” IEEE Electron Dev. Lett., vol. 34, p. 1091, 2013. DOI: 10.1109/LED.2013.2272649
2. M. Asiatici et.al., "Capacitive inertial sensing at high temperatures of up to 400°C," IEEE Sensors and Actuators A, vol. 238, p. 361, 2016. DOI: 10.1016/j.sna.2015.12.025
3. A. D. Smith et al. “Electromechanical Piezoresistive Sensing in Suspended Graphene Membranes,” ACS Nano Letters, vol. 13, p. 3237, 2013. DOI: 10.1021/nl401352k
4. S. Vaziri, et al., “A Graphene-Based Hot Electron Transistor,” ACS Nano Letters, vol. 13, p. 1435, 2013. DOI: 10.1021/nl304305x
5. S. Sani et.al., “Mutually synchronized bottom-up multi-nanocontact spin-torque oscillators,” Nature communications, vol. 4, 2731, 2013. DOI: 10.1038/ncomms3731
6. S. Bonetti et.al., “Direct observation and imaging of a spin-wave soliton with p-like symmetri,” Nature communications, vol. 6, 8889, 2015. DOI: 10.1038/ncomms9889
7. F. Niklaus et.al., "Adhesive wafer bonding," J. Appl. Phys., vol. 99, p. 031101, 2006. DOI: 10.1063/1.2168512
8. C.-M. Zetterling, “Integrated circuits in silicon carbide for high-temperature applications,” MRS Bulletin, vol. 40, p. 431, 2015. (Invited) DOI: 10.1557/mrs.2015.90
9. H. Elahipanah et.al., "5.8-kV Implantation-Free 4H-SiC BJT With Multiple-Shallow-Trench Junction Termination Extension," IEEE Electron Dev. Lett., vol. 36, p. 168, 2015. DOI: 10.1109/LED.2014.2386317
10. J. Rabkowski et.al., "Design steps towards a 40-kVA SiC inverter with natural-convection cooling and an efficiency exceeding 99.5%," IEEE Trans. Ind. Appl., vol. 49, p. 1589, 2013. DOI: 10.1109/TIA.2013.2258132