Postdoc Research

High-frequency Transistor for Operation in Harsh Space Environments

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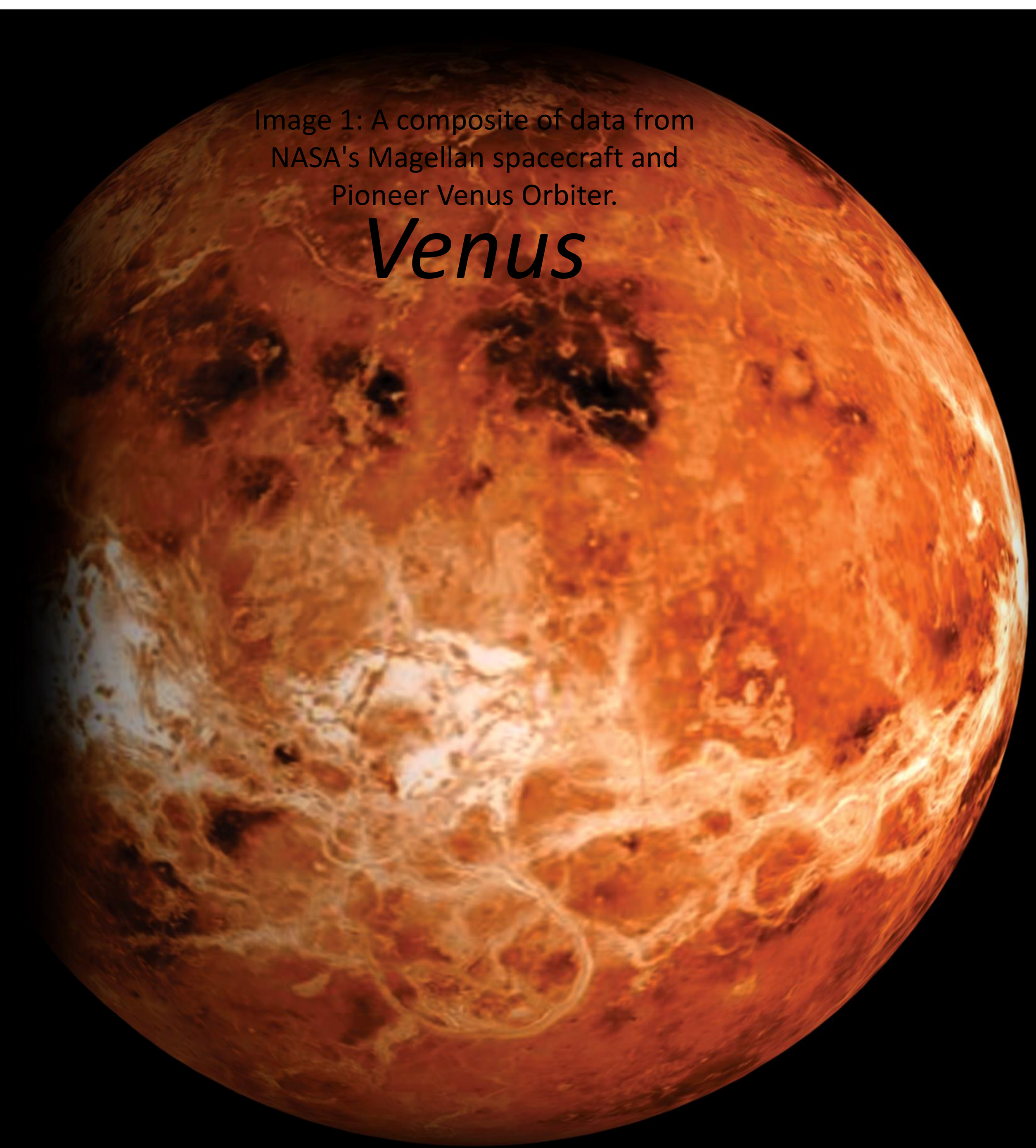


Image 1: A composite of data from NASA's Magellan spacecraft and Pioneer Venus Orbiter.

Background

Science Gap How can our sister planet Venus' with such similar shape and distance to the sun, be so vastly different from Earth? To answer this we need to study it in more detail to understand its creation, evolution and climate. Discovery missions on how the forces of volcanism, tectonics and chemical weathering, could give us entirely new observations, but for that we need robust and sensitive electronics due to the harsh environments found at Venus.

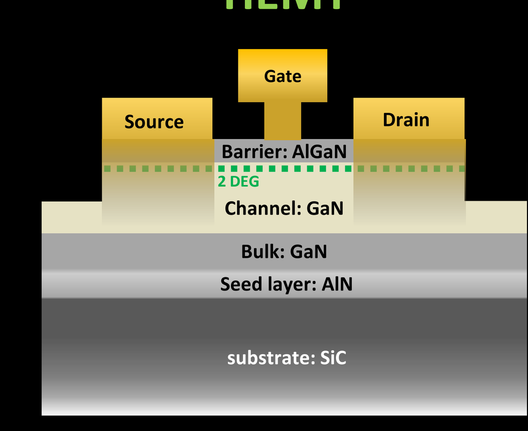
Technology Gap Electronic components, such as transistors, Hall-effect sensors, and detectors, are typically made of silicon due to their compatibility with integrated circuits, ease of manufacturing, and low cost. However, exposing silicon-based components to temperatures beyond 200°C makes them go into breakdown mode or requires external cooling to operate in high-temperature environments. Implementing such cooling systems not only requires additional power but also contributes to additional size, weight, and overall costs, which, in general, requires the system to be much more complex. Therefore, developing components that can operate at extreme temperatures with high stability and no additional cooling is essential for higher efficiency, higher reliability, and lower cost.

Objectives

This work aims to develop the next generation of components for sensing technology, which must withstand the challenging circumstances present during space missions and on the journey out from our atmosphere:

- Extreme temperature swings
- Highly ionizing radiation
- Intense mechanical vibrations of launch and landing

HEMT

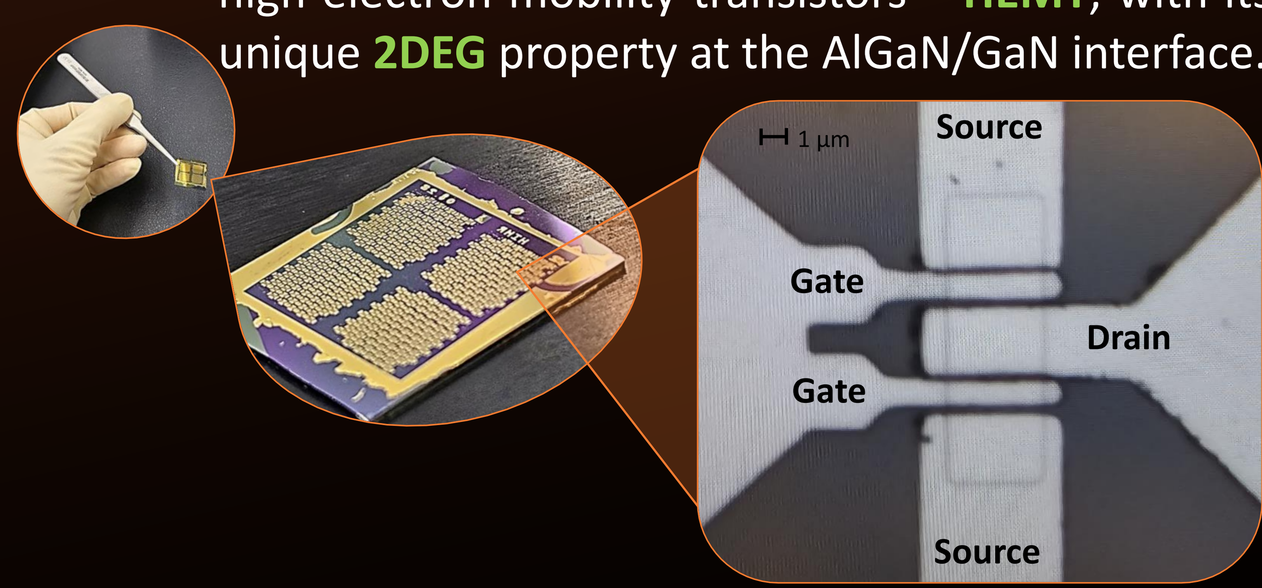


Approach and Results

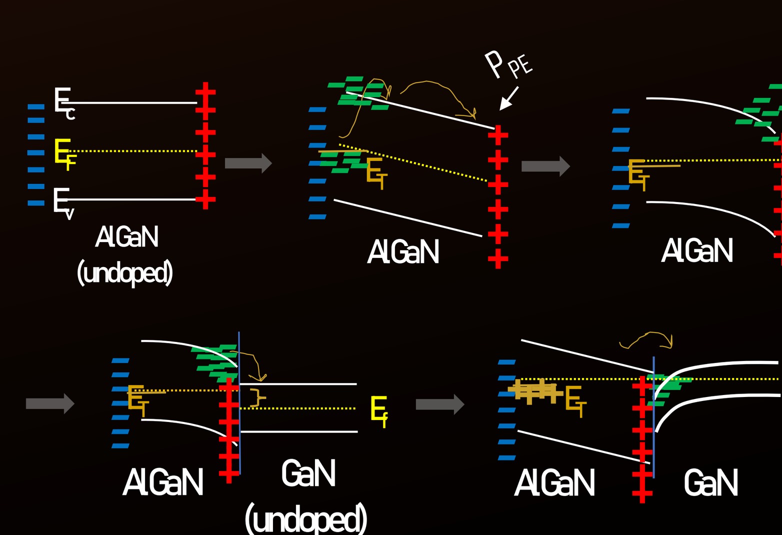
AlGaN/GaN have been chosen as the main device material in this project – a radiation tolerant heterostructure with advantageous properties suitable for the harsh environment present in space.

Advantagous Material Properties	GaN	Si
Bandgap (eV)	3.4	1.1
Breakdown field (MV/cm)	3.4	0.3
Electron mobility (cm^2/Vs)	2000	1400
Saturated Electron Velocity ($x10^7$ cm/s)	1.3	1
Thermal conductivity (w/cm°C)	1.3	1.3

A key component for high-frequency sensing and detection technologies have been fabricated: the high electron mobility transistors – **HEMT**, with its unique **2DEG** property at the AlGaN/GaN interface.



Origin of **2DEG** in AlGaN/GaN:



Spontaneous and piezoelectric polarization → Causes electric field and band bending

Trap sites on the top surface → fermi level (E_F) pinned to energy of traps (E_T)

The band bending makes electrons from trap sites to travel to interface → gets accumulated; 2DEG is formed

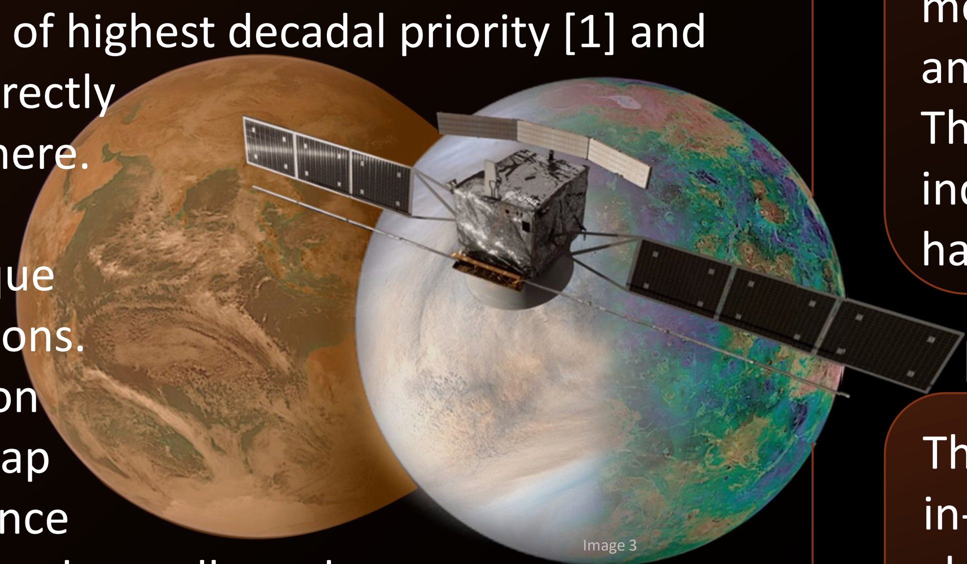
For Fermi level equilibrium, electrons propagate to interface → Another band bending → The 2DEG stuck in a quantum well, with high mobility

Benefits to NASA/JPL

A "triple crown" moment for the Venus science community

The devices developed in the project are very well suited for the following three large missions:

The **DAVINCI+** atmospheric entry probe can provide the only direct measurements of the Venus atmosphere – for the first time since NASA's Pioneer Venus probe in 1978 and the USSR VEGA Balloons in 1985. Many of the proposed measurements are of highest decadal priority [1] and can only be acquired by traveling directly through the planet's harsh atmosphere.

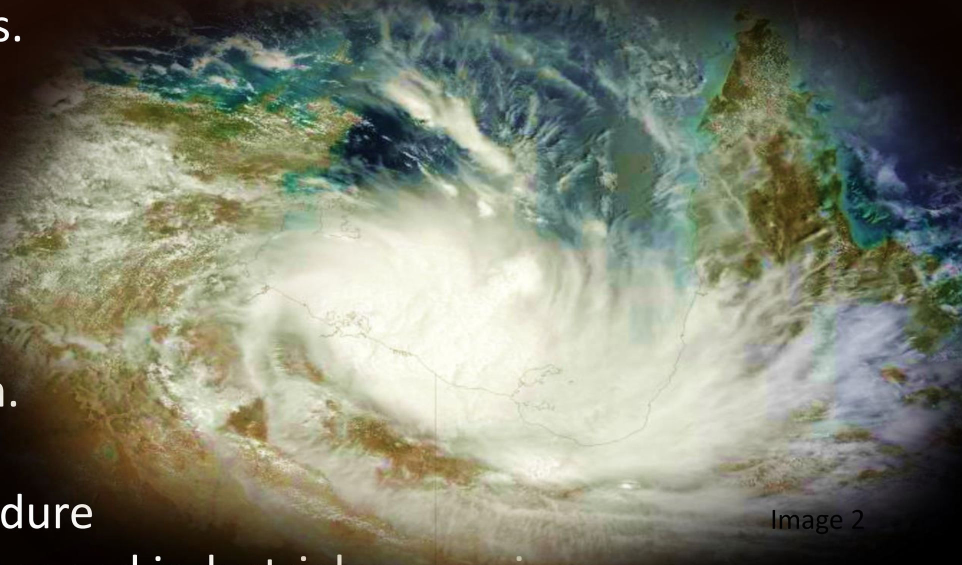


The global topography data generated by **VERITAS** is also a unique contribution among the three missions. It will provide us with high-resolution topography and a global location map for Venus that will serve as a reference system for all past and future surface data collected.

NASA is a partner with ESA on the **EnVision** mission. JPL, in specific, will provide the VenSAR radar and will have responsibility of the overall instrument management and provision. EnVision VenSAR is part of NASA's Discovery Program.

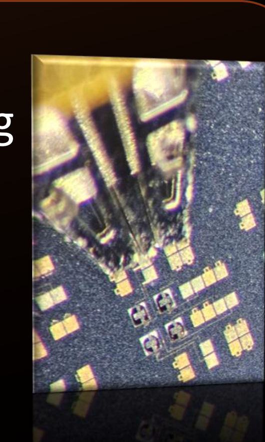
Significance

The scientific return of these components will permit insight into planetary bodies' (e.g., Europa, Titan, Mercury, Venus, etc.) internal compositions and dynamics in extreme cold and extreme heat and close to their surfaces. In addition, the devices' high-frequency capabilities will enable earth science possibilities. This would enable studying climate change and cloud formation by measuring the water absorption in clouds and the density in both solid and liquid form. This work would also be of help to several industries in need of technology that can endure harsh environments, such as the energy sector and industrial processing.



Future Work

The next step in this work is to integrate the HEMT in a readout chain for an in-house developed IR resonator array [2]. The array is meant to be operating close to the surface of Venus for detailed IR-imaging in the harsh conditions.



Further on, an envisioned MEMS, as a sensing platform, can be developed, with the GaN-based HEMTs as key components. This would enabling sensitive readout of several monolithically integrated components, such as a magnetometer, UV detector, gas sensor, and a power amplifier, etc.

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Abbreviations:
HEMT: high-electron-mobility-transistor
2DEG: two-dimensional electron gas
DAVINCI+ :Deep Atmosphere Venus Investigation of Noble gases, Chemistry, and Imaging
VERITAS: Venus Emissivity, Radio Science, InSAR, Topography, and Spectroscopy
IR: infrared,
UV: ultraviolet
MEMS: Microelectromechanical Systems

References:
[1] Origins, Worlds, and Life: A Decadal Strategy for Planetary Science and Astrobiology 2023-2032 (2022) ISBN 978-0-309-47578-5
[2] M. B. Coskun and M. Rais-Zadeh, "Thermal Infrared Detector Sparse Array for NASA Planetary Applications," *2021 5th IEEE Electron Devices Technology & Manufacturing Conference (EDTM)*, Chengdu, China, 2021, pp. 1-3, doi: 10.1109/EDTM50988.2021.9420853.

Credit:
Image 1: NASA/JPL-Caltech
Image 2: Jeff Schmaltz (MODIS Land Rapid Response Team, NASA GSFC)
Image 3, credits: European Space Agency / Paris Observatory / VR2Planets

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