Radiation-Hardened Millimeter-Wave Detector for Neutron and ECH Environments

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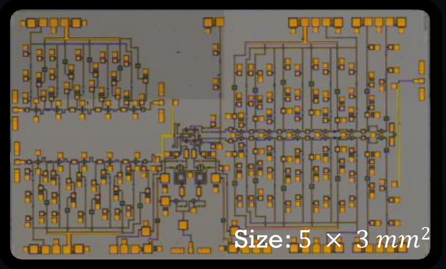
General Atomics
Suk-Ho Hong

Conell University
James Hwang



GaN receiver chip
for harsh environment

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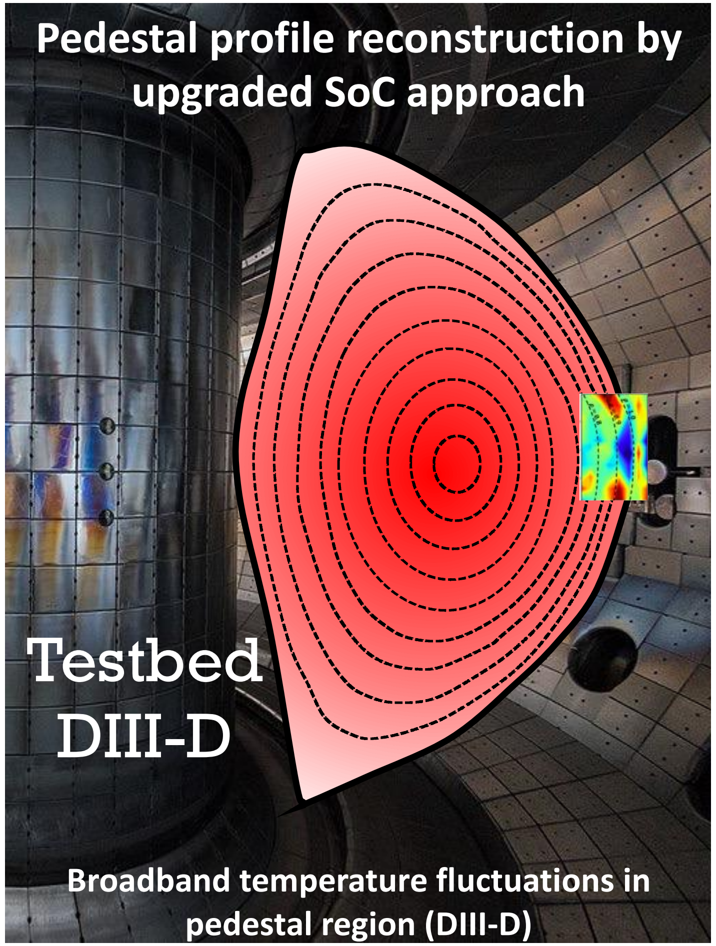
Field Validation and High TRL: Essential for Fusion



Functioning as an essential platform for technological testing and validation, the DIII-D offers not only a fully developed fusion-relevant environment with robust work and safety procedures, but also a deep culture of collaboration and an exceptional team of experts.

Neutron Flux   Neutron Fluence   ECH Auxiliary Heating

Harsh environment for sensors

Rad-Hard   **Self-Renewing**

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Development and Performance Validation

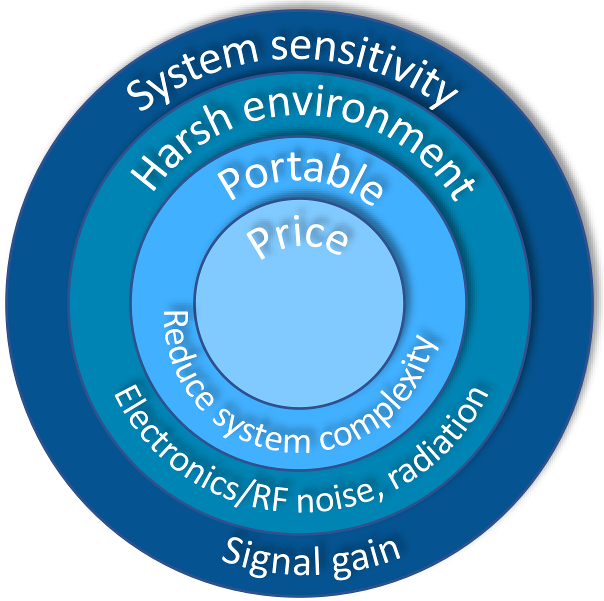
Commercial electronics

Rad-tolerant electronics

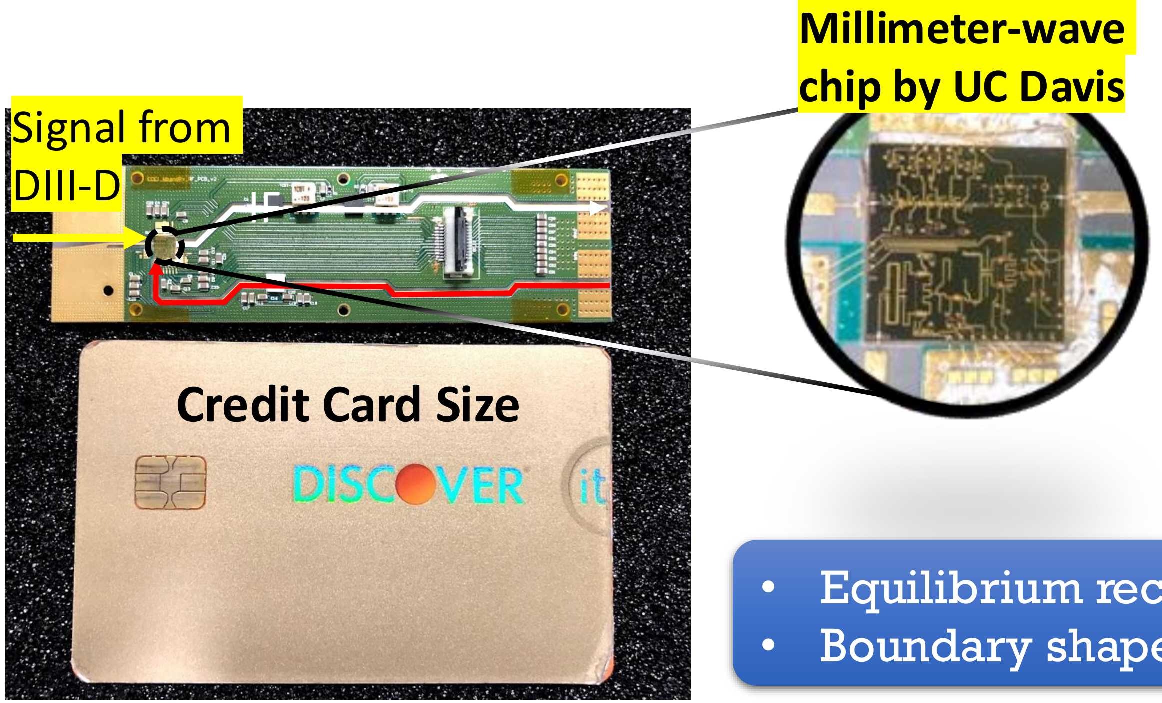
Rad-hard electronics

Rad-tolerant components can tolerate more radiation doses and/or fluxes than standard consumer electronics, but they tolerate lower radiation exposure than radiation hardened devices.

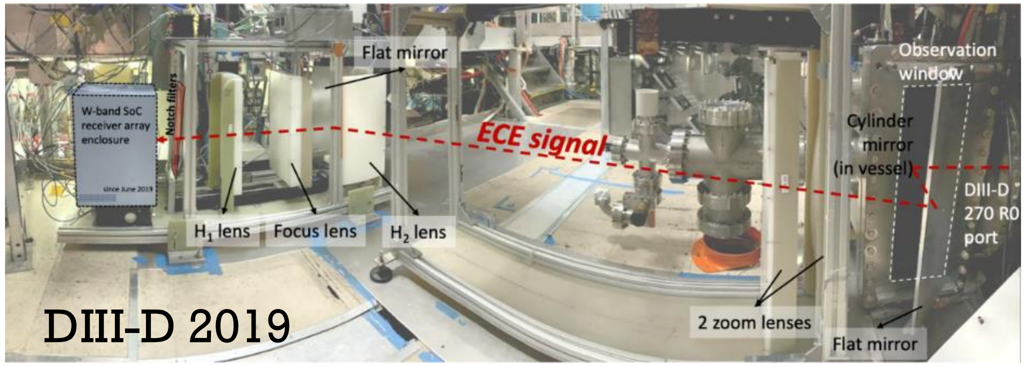
Rad-hard electronics play an essential role in industries where exposure to extreme radiation levels can cause serious malfunctions or failures. These components are specifically designed to withstand harsh environments (such as fusion reactor).



Rad-tolerant burning plasma diagnostics attempts



Zhu, Y., et al.." Review of Scientific Instruments 91.9 (2020).



- Equilibrium reconstruction
- Boundary shape and position

- Disruption prediction (AI)

- Energetic particle control

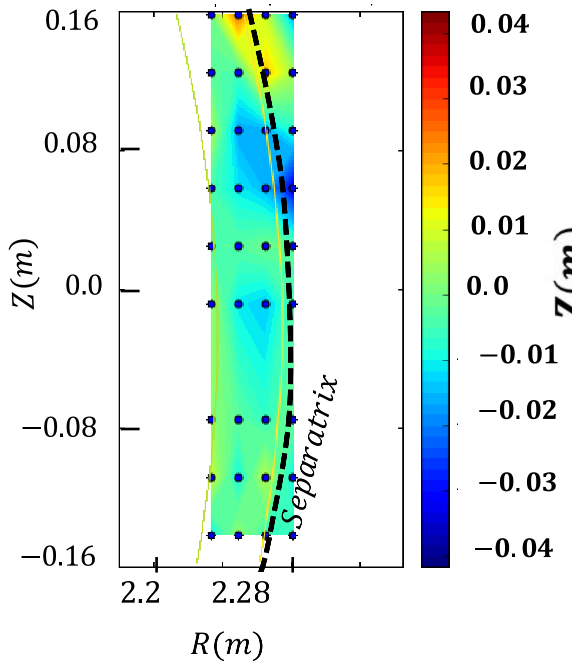
6-YEAR

MAINTENANCE-FREE RECORD (2025)

Measurement breakthroughs and applications

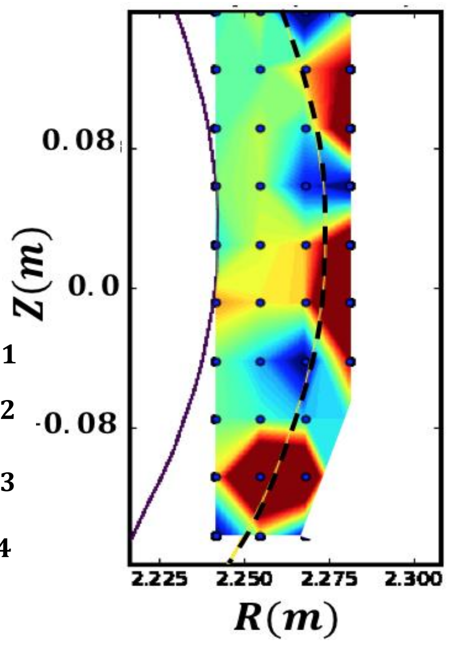
DIII-D

Edge Localized Mode



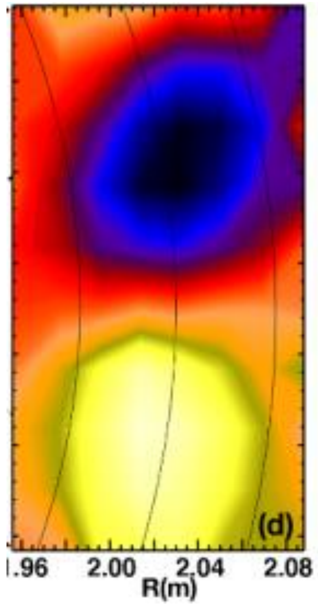
Yu, Guanying, et al. Physics of Plasmas 30.6 (2023).

Edge bloby turbulence



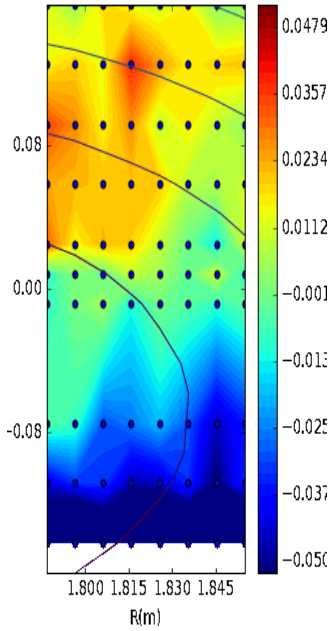
Khabanov, F. O., et al. Nuclear Fusion 64.12 (2024): 126056.

Alfven eigenmode



Van Zeeland, Michael A., et al. Nuclear Fusion 64.5 (2024): 056033.

Sawtooth crash

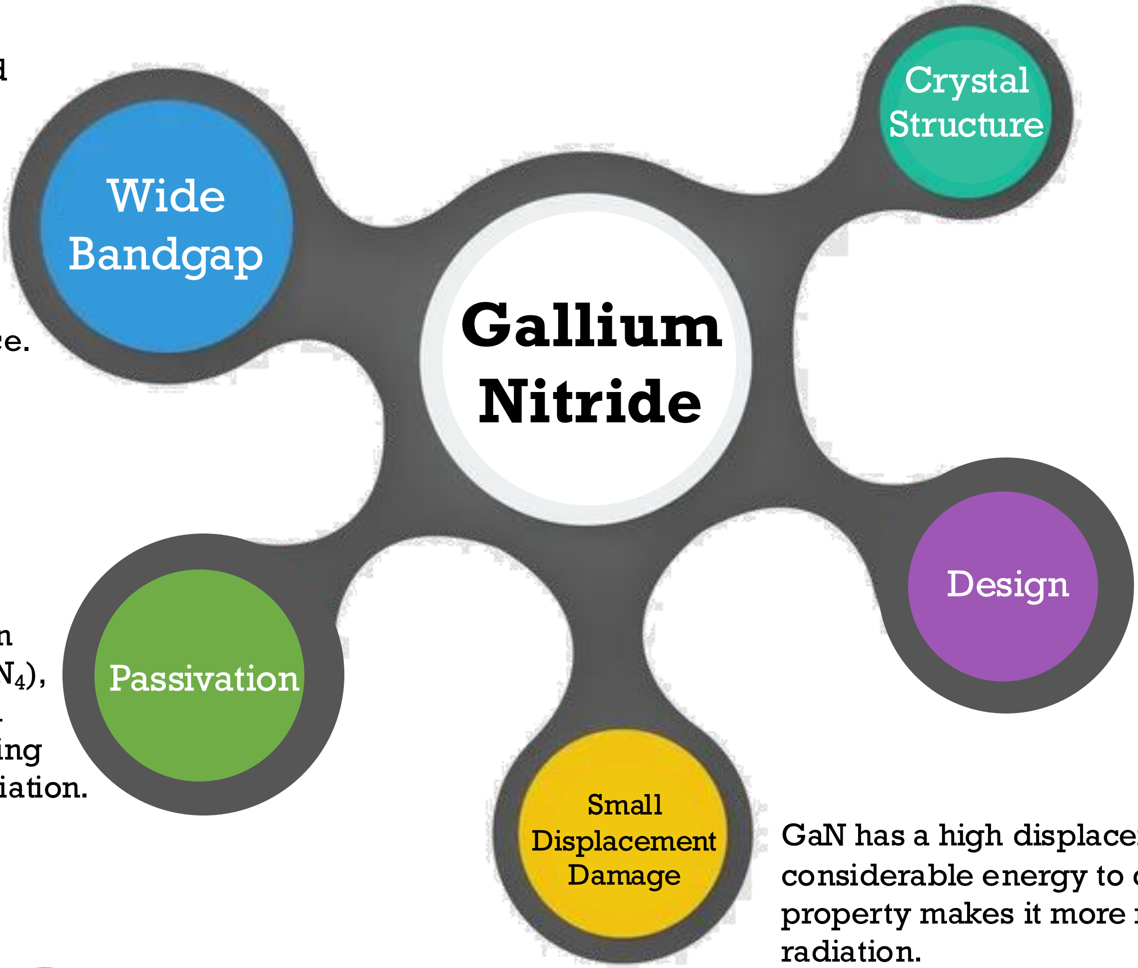


Under review

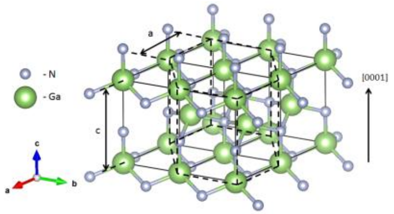
- **Plasma edge shape and position**
  - Yu, Guanying, et al. *Review of Scientific Instruments* 93.10 (2022).
- **Suprathermal and runaway electron measurement**
  - Yu, Guanying, et al. Review of Scientific Instruments 95.7 (2024).
  - Yu, Guanying, et al. *Journal of Plasma Physics* 90.6 (2024): 985900601.
- **Disruption Prediction**
  - Li, Xiaoliang, et al. Plasma Physics and Controlled Fusion (2025).

Rad-hard semiconductor – Gallium Nitride

GaN has a wide bandgap (**3.4 eV**) and strong atomic bonds, which make it inherently more resistant to radiation-induced defects compared to other materials like silicon (Si, 1.12 eV). This means it can withstand higher levels of ionizing radiation without significant degradation in performance.



GaN typically has a wurtzite crystal structure, which contributes to its radiation resistance. This structure is inherently more stable under radiation bombardment compared to other crystal structures.



The design of GaN devices can also contribute to their radiation tolerance. For example, using thicker epitaxial layers or incorporating specialized structures can help mitigate the effects of radiation-induced defects.

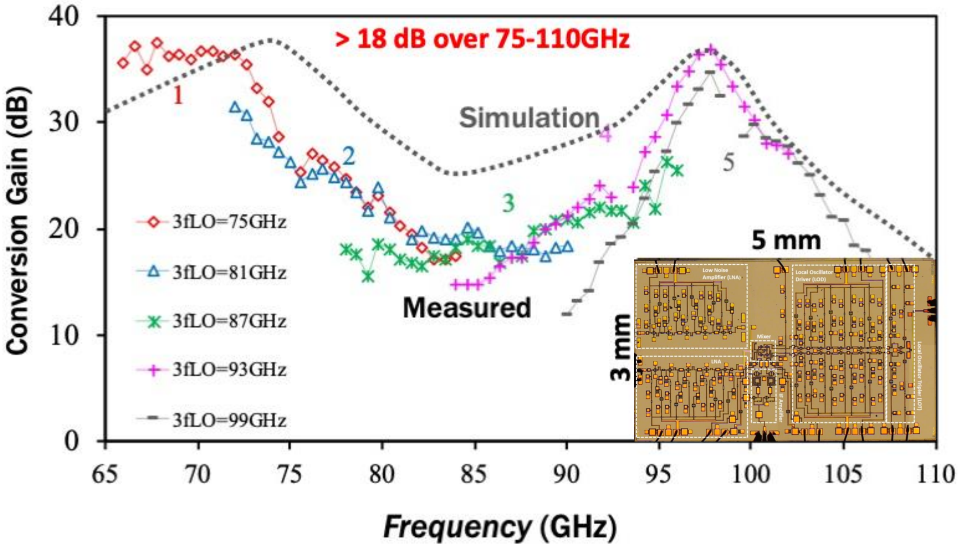
GaN has a high displacement energy threshold, meaning it requires considerable energy to displace atoms from their lattice positions. This property makes it more resilient to displacement damage caused by radiation.

The surface of GaN devices can be passivated with materials like silicon dioxide (SiO_2) or silicon nitride (Si_3N_4), which can further enhance radiation tolerance by protecting the underlying GaN material from the effects of radiation.

Rad-hard semiconductor

75-110-GHz GaN Receiver by UC Davis

HRL 300 GHz foundry

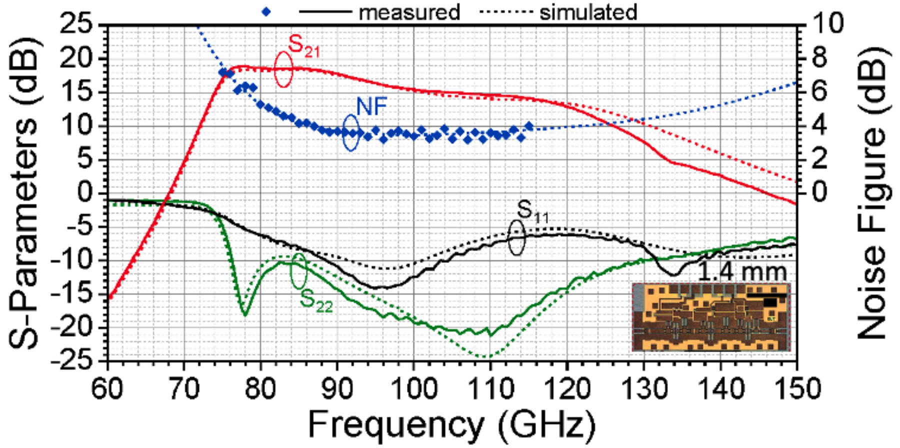


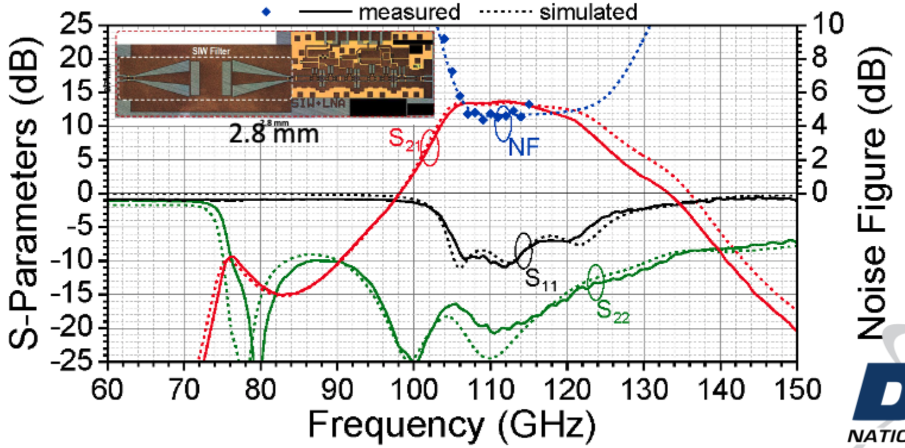
Technology Readiness Level 5 (2025)

Component and breadboard validation in relevant environment

74-119 GHz GaN Low-Noise Amplifier by Cornell

Fraunhofer 200 GHz GaN foundry





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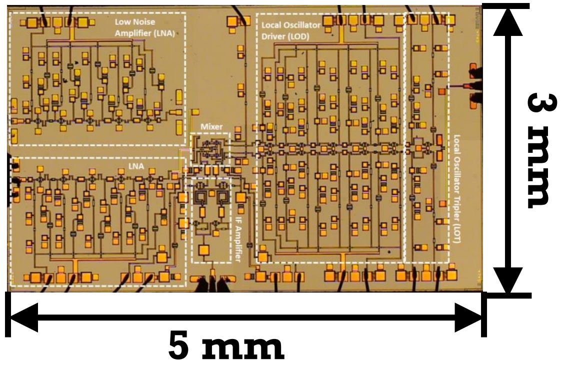
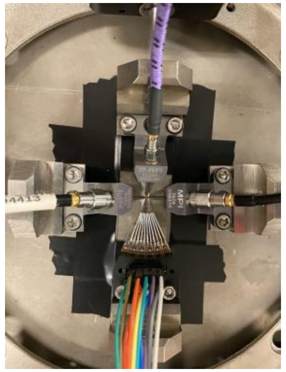
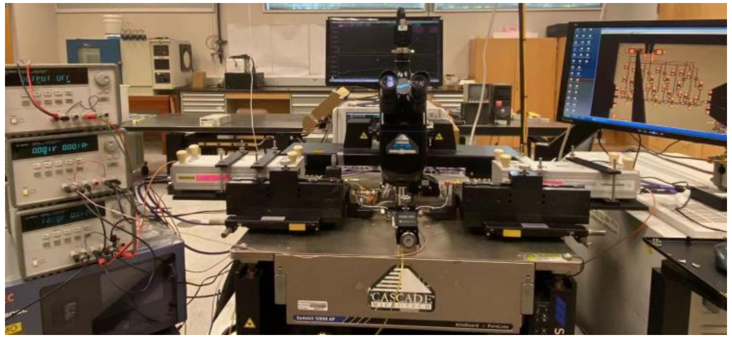
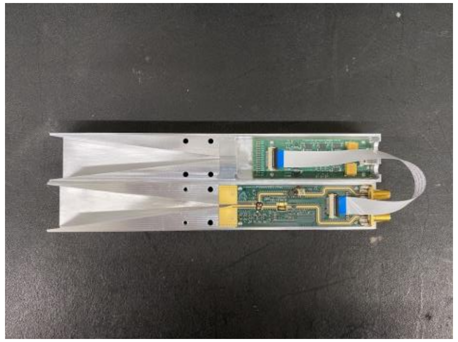
Rad-hard Millimeter-wave Sensor Development

Li, Xiaoliang, et al. *Journal of Instrumentation* 19.06 (2024): P06046.









Architecture design
Wafer tape-out

On-wafer testing in laboratory
RF performance validation

Module development

TRL 2-4

- GaN millimeter-wave frequency technology concept formulated
- Initial chip design and numerical simulation proof-of concept

TRL 5

- Prototype GaN mm-wave receiver chip tape out
- Receiver DC-performance testing in lab
- Receiver RF-performance testing in lab
- Receiver noise figure performance testing in lab
- Thermal management for full-power testing in lab

TRL 6

- Package module design
- Prototype GaN receiver module development

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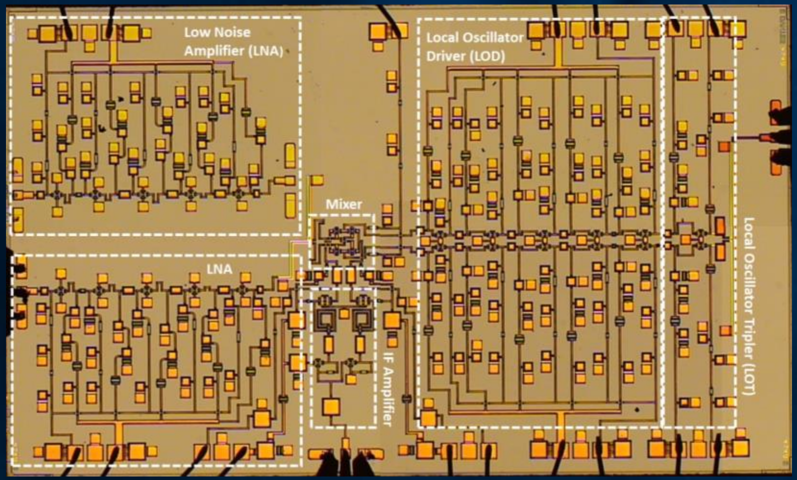
Photograph by Dr. S. Qiu

2016	Architecture design
2017	Package tech validation
2018	Radiation tolerant attempts
2019	Prototype on DIII-D
2021	Radiation hardened attempt
2022	Physics campaigns
2024	GaN generation
2025	Performance validation in lab.
	Iteration and Improvements



GaN-based W-band receiver chip

W-band receiver module
(by UC Davis)

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ECH Protector (Notch Filter) Development

ECH notch filter for Transmitter and Receiver Module Protection (>60 dB)

60 GHz, 105 GHz, 110 GHz, 117.5 GHz, 140 GHz, 170 GHz

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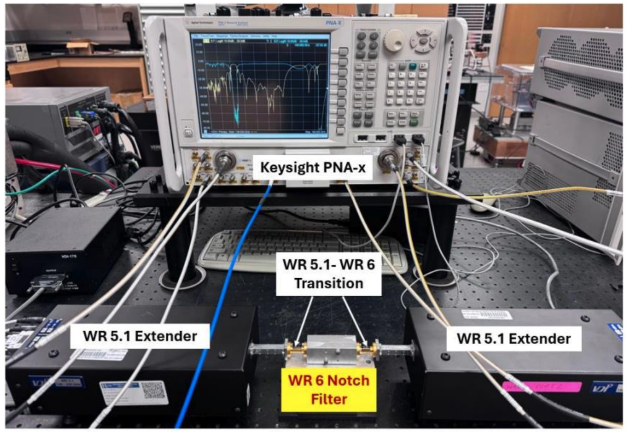
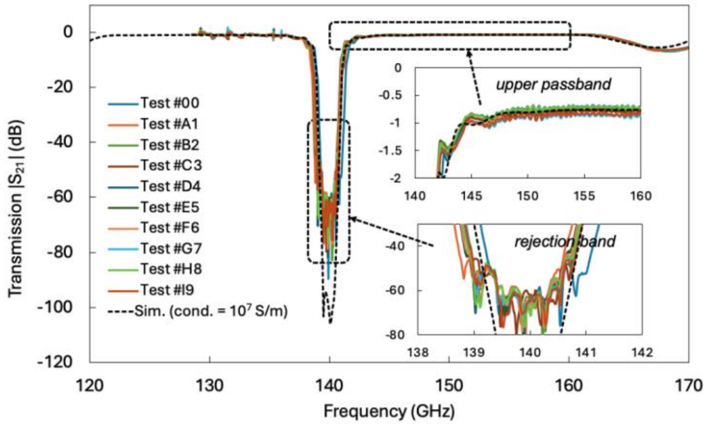
1. Qiu, Shasha, et al. Review of Scientific Instruments 95.2 (2024).
2. Himes, Logan, et al. Journal of Instrumentation 19.10 (2024): P10024.
3. Luo, Chen, et al. *Plasma Science and Technology* (2025).
4. *Luo, Chen, et al. Fusion Engineering and Design 214 (2025): 114925.*

5 MW On-site validation → 20 MW Prototype in Lab





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Summary

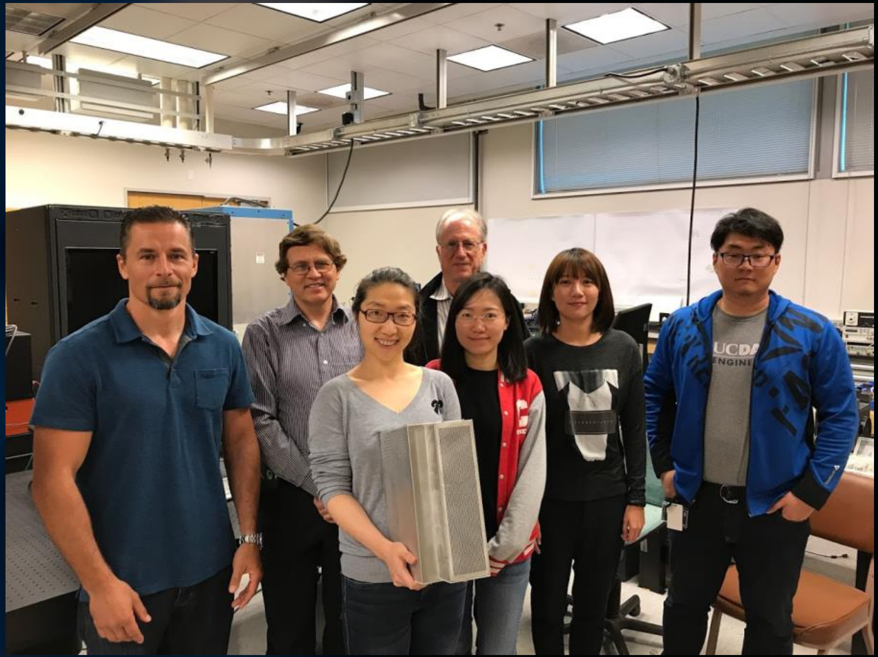
Important Testbed for
fusion enabling technologies

Rad-Hard Millimeter-wave Semiconductor Sensor:

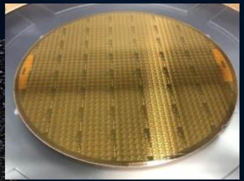
1. Plasma control; Disruption prediction; Particle Managing
2. Radiation hardened; Portable; Maintenance-free; Mass production
3. SECURED SUPPLY CHAIN **(all in U. S.)**

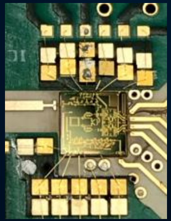
ECH protector (Notch Filter):

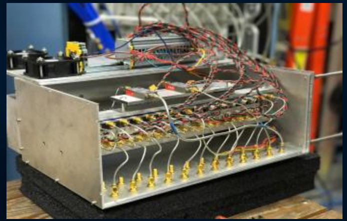
1. World-wide application (U.S. Europe, Asia)
2. Cover multiple ECH frequencies (60, 105, 110, 117.5, 140, 170 GHz)
3. On-site validation (5 MW), new approach prototype has been successfully developed (20 MW).



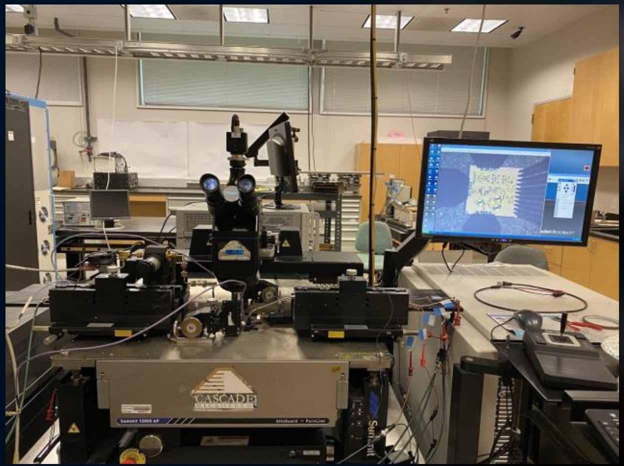

DISCOVER it








VISITOR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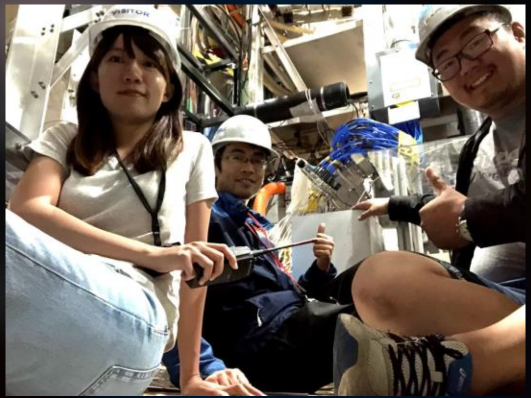

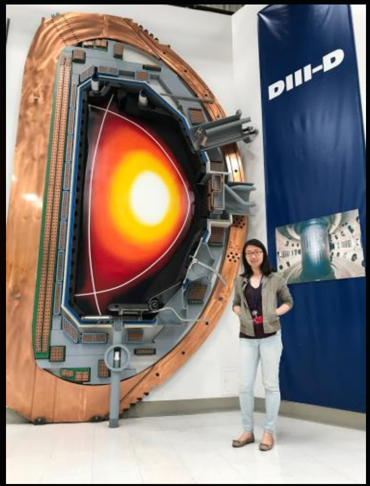
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