Applications of Robust, Radiation Hard AlGaN Optoelectronic Devices in Space Exploration & High Energy Density Physics

Ke-Xun Sun
Stanford University &
National Security Technologies
CLEO May 2011, Baltimore, Maryland

AlGaN UV LED and Photodiode Collaboration

Sponsor / Program Management

- NASA Ames Research Ctr -- Pete Worden, BJ Jaroux
- KACST --- Turki Alsaud, Haithem Altwaijry
- Stanford University -- Robert Byer, Sasha Buchman
- National Security Technologies (DOE Contract No. DE-AC52-06NA25946-1221)

Science and Engineering Team

• Stanford University

- Ke-Xun Sun (Lead)
- Abdul Alfauwaz
- Ahmad Aljadaan
- Hamoud Aljabreen
- Muflih Alrufaydah
- Salman Althubiti
- Karthik Balakrishnan
- Eric Hultgren
- Steve Rapinchuk
- Seiya Shimizu
- Andreas Zoellner

Graduated Students:

- Brett Allard (AA Engr 2005)
- Sei Higuchi (AA Ph.D 2009)
- Nick Leindecker (EE MS 2008)
- Patrick Lu (EE Ph.D 2009)

• NASA Ames Research Center

- John Goebel
- John Hanson
- Kuok Ling
- Robert Ricks
- Michael Soulage

• KACST

- Abdulla Alangary
- ...

• National Security Technologies (NSTec)

- Ke-Xun Sun
- Anita Behnke
- Rob Buckles
- Larry MacNeil
- William Warthan

• Sensor Electronics Technologies (SETi)

- Remis Gaska
- Yuri Bilenko
- Xuhong Hu
- Max Shatalov
- Wenhong Sun
- Jinwei Yang

Outline

Applications of Robust, Radiation Hard AlGaN Optoelectronic Devices in Space Exploration & High Energy Density Physics

- Space Exploration Applications
- High Energy Density Physics Applications
- UV LED and Photodiode Radiation Hardness
- UV LED and Photodiode Space Qualification
- UV LED AC Charge Management
- UV LED Satellite Payload Instruments
- UV LED Satellite will be launched 2nd Half 2012
- Outlook

Next Generation Space Science Missions

LISA

**Breakthrough
Instruments**

**Precision
Satellite Control**

**Geodesic
Missions**

**Deep Space
Exploration**

**DECIGO
BBO**

Space Flight Environments and Requirements

Radiation Environment for 3 and 7 Solar Active Years at LISA Solar Orbit

Figure 1: Solar proton fluences for a 95% confidence level are presented for 3 and 7 solar active years.

Launch Shocks and Vibrations

Figure 3.1 – Typical Longitudinal Steady-state Static Acceleration (first three stages flight)

Charging effects Radiation damages

Extreme Temperature Variations

.....

Radiation Challenges for Europa Jupiter System Missions (EJSM)

- EJSM is the flagship mission for NASA/ESA outer planet exploration programs
- JEO to fly over Europa
- JGO to fly over Ganymede
- total 1×10^{12} protons/cm² fluence expected for mission lifetime
- Radiation challenge unprecedented for NASA missions

Graph from T. Y. Yan presentation "Risk Mitigation Effort Overview" at EJSM Workshop 2009, Baltimore

NIF Neutron Fluence

- Ignition shot: $N \sim 10^{15}$ neutrons
- Neutron energy ~ 15 MeV
- Detector 1 m away from target
- Neutron emission per shot $\sim 10^{15}$

$$F = \frac{N}{4\pi R^2} \approx 8 \times 10^9 \text{ 1/cm}^2$$

- One year fluence (700 shots)

$$F_{\text{1year}} \approx 5.6 \times 10^{12} \text{ 1/cm}^2$$

- Proton irradiation test fluence

$$F_{\text{test}} \approx (1 - 5) \times 10^{12} \text{ 1/cm}^2$$

- Current “Rad-Hard” films, requiring frequent replacements
 - Radiation hazard for film workers
 - In-efficiency
 - Low performance
- Radiation hard semiconductor detectors as permanent sensors
 - No radiation hazard by eliminating film operations
 - Efficiency with real-time data access
 - High performance
 - Long term needs by LIFE and spent fuel re-use

Radiation Hardness Requirements at New Generation HEDP Facilities

Facility	Particle & Energy	Total # Particles Per Shot (or beam brightness)	One Shot Total Fluence at 1 m away (1/cm ²)	One Year Total Fluence at 1 m away (1/cm ²)	1 mm ² Detector Total Particle counts
NIF	neutrons 15 MeV	10 ¹⁵	~8x10 ⁹	~5.6x10 ¹² (700 shots)	~5.6x10 ¹⁰
LCLS	X-ray 8 keV	10 ¹²	10 ¹²	2x10 ²⁰ (250 day operation)	2x10 ¹⁸
LHC	Proton 1 GeV	10 ¹⁵ ~ 10 ¹⁶	10 ¹⁵ ~ 10 ¹⁶	Higher Flux	Higher Flux

UV LED Spectrum Measured at Stanford

- Peak wavelength: 257.2 nm, comparable to Hg line 254 nm
- FWHM: 12.5 nm, good photoemission for Au coatings
- Total UV power: 0.144 mW, sufficient for charge management

UV LED Power and Spectral Stability

Lifetime tests started March 2006, over 5 years. Still Running.

Operation Lifetime in Nitrogen > 26,000 hours

Operation Lifetime in Vacuum > 30,000 hours

K.-X. Sun et al "UV LED Operation Lifetime and Radiation Hardness Qualification for Space Flights," Journal of Physics CS, doi: 10.1088/1742-6596/154/1/012028

UV LED Radiation Hardness Test Proton Irradiation Setup at UC Davis

UC Davis Proton Beam Facility

UV LED Radiation Hardness Using Proton Irradiation

UC Davis proton energy:
59 MeV for 80pA & 500 pA
63.8 MeV for 15,000 pA

Space proton energy:
2~5 MeV

Total fluence: > 100 year
proton fluence in LISA orbit

Reference for proton test of other
LED and laser diodes:
A. H. Johnston and T. F.
Miyahira, "Characterization of
Proton Damage in Light-Emitting
Diodes", IEEE Trans. Nuclear
Science, **47** (6), 1999

Sun, Leindecker, et al, "UV LED Qualification for Space Flight",

AlGaN Photodiode Proton Irradiation Test

Work at National Security Technologies, LLC is done under Contract No. DE-AC52-06NA25946 with the U.S. Department of Energy with the U.S. Department of Energy. DOE/NV/25946--1221

AlGaN UV Photodiode Radiation Hardness Test

UC Davis Proton Beam Facility

Work at National Security Technologies, LLC is done under Contract No. DE-AC52-06NA25946 with the U.S. Department of Energy with the U.S. Department of Energy. DOE/NV/25946--1221

AlGaN Photodiode UV Light Response vs. Proton Fluence

- Photodiode in photovoltaic mode
- For each fluence level, measure the photodiode readout for UV light on and off
- The normalized differential reading is defined as the photodiode response to UV light

Work at National Security Technologies, LLC is done under Contract No. DE-AC52-06NA25946 with the U.S. Department of Energy with the U.S. Department of Energy. DOE/NV/25946--1221

- [1] K.-X. Sun and L. MacNeil, "Radiation Hardness of AlGaN Photodiodes," 4th NASA/ESA EJSM Workshop, Jet Propulsion Laboratory, July 26-29, 2010
- [2] K.-X. Sun and L. MacNeil, "GaN Radiation Hard Properties and Detectors," SPIE Hard X-ray, Gamma Ray, and Neutron Detection, San Diego, August 1-5, 2010

NASA Ames Shake & Bake Tests 2009

Shake Test Platform
In Z-direction (upper)
In X,Y direction (lower)
Vibration profile: 3g and 7g spread
spectrum up to 2 kHz

Right column:
Thermal-Vac chamber
open-door view (upper),
closed door view (lower)
-30~+60 C ramp + soak

AlGaN UV LED Space Qualification Shake and Bake Tests

UV LED Beam Profile, Spectra, and V-I-P Curves Before and After Shake & Bake

Automated Test Setup 2010

Karthik Balakrishnan Poster

Beam profiler

Spectrometer

Motorized
LED mount &
Rotary stage

LabView Control

Power meter

Fiber Input

NASA Ames Space Qualification Tests 2010

- The first uses for the automated testbed was a space qualification test of several UV LEDs at NASA Ames Research Center. The test met the qualification requirements set by MIL-STD-1540E:
 - **Thermal Vacuum: -34 to +71C for 4 cycles**
 - **Vibration: RMS 14g, 6dB above expected profile for 3 minutes/axis**
 - **Thermal cycle at ambient pressure: -34 to +71C for 23 cycles**

UV LED V-I, I-P Curves, Spectrum Before and After Bake and Shake Tests

**Electrical V-I curves
reflects intrinsic
semiconductor
quality**

UV LED AC Charge Management

UV LED Charge Management System

- Light weight, compact size, low power consumption
- Peak wavelength 255 nm, comparable to Hg line 254 nm
- AC charge management at frequencies *out-of signal band* (e.g. at cap bridge freq.)
- Long operation time for *continuous* charge management

Progresses in UV LED space qualification:

- Extreme radiation hardness tested using proton irradiation
- Operational lifetime tests in nitrogen > 26,000 hours, in vacuum > 30,000 hours
- Conclusively demonstrated the appropriateness for flying UV LED charge management system

UV LED AC Charge Management

INSTITUTE OF PHYSICS PUBLISHING

CLASSICAL AND QUANTUM GRAVITY

Class. Quantum Grav. **23** (2006) S141–S150

doi:[10.1088/0264-9381/23/8/S19](https://doi.org/10.1088/0264-9381/23/8/S19)

LED deep UV source for charge management of gravitational reference sensors*

**Ke-Xun Sun, Brett Allard, Saps Buchman, Scott Williams
and Robert L Byer**

Hansen Experimental Physics Laboratory, Stanford University, CA 94305-4085, USA

E-mail: kxsun@stanford.edu

Received 29 September 2005, in final form 3 January 2006

Published 28 March 2006

Online at stacks.iop.org/CQG/23/S141

UV LED vs. Mercury Lamp

Charge Management Systems

<i>Category</i>	<i>UV LED CMS</i>	<i>Mercury Lamp CMS</i>
Electrical Power Consumption	1 W	15 W
EMI	Minimal	Large due to RF excitation
Weight	0.3 kg	3.5 kg
Dimension of the CMS system	10 cm x 8 cm x 3 cm	17 cm x 13 cm x 17 cm
UV emission power	~120 μ W	~100 μ W
UV Power at the fiber tip	~16 μ W	~11 μ W
UV Wavelength, central	257 nm	194 nm & 254 nm
UV Wavelength, spread	12.5 nm	Doppler Broadening
Fast modulation capability	Yes – Intensity, pulse train frequency and phase, etc.	No
Charge management method	AC & DC	DC only
Charge management frequency	Out-of signal band	In signal band
Equivalent dynamic range	100,000	100
Charge management resolution	high	low
Charge management speed	high	low

UV LED Charge Management Experimental Setup

- GP-B heritage
- **Au coating on proof mass and housing to simulate LISA GRS**
- Fiber connected UV LED driven by modulated current source
- **Housing electrode modulation phase-locked to UV modulation**
- UV light shining on proof mass and reflected onto housing electrode
- **Sensitive electrometer to measure the proof mass potential**

Positive Charge Transfer

UV LED and bias voltage modulated at 1 kHz

May 6, 2005 Positive Charge Transfer Phase Configuration

UV phased to positive AC ½ cycle
Electrons fly to housing electrode
Proof mass potential increase

Negative Charge Transfer

UV LED and bias voltage modulated at 1 kHz

May 6, 2005 Negative Charge Transfer Phasing

UV phased to negative AC ½ cycle

Electrons fly to proof mass

Proof mass potential decreases

AC Charge Management Shows Promising Characteristics

UV LED and bias voltage modulated at 10 kHz

UV LED Space Qualification Environmental Tests

Category	Test	Performance
Lifetime	Operation N ₂ environment	>26,000 Hours and on, no UV power degradation, and significant spectral shift
Lifetime	Operation in vacuum 10 ⁻⁷ tor	>20,000 Hours and on, no UV power degradation
Radiation Hardness	Proton Irradiation	2x10 ¹² protons/cm ² irradiation, no power and spectra shift
Shake tests (I) (May 2009)	X,Y,Z 3g & 7g spread spectrum shake (Delta II Vehicle)	No significant changes in power, spectral, and V-I-P characteristics
Bake tests (I) (May 2009)	Thermal Vac 10 ⁻⁶ tor 2 Temperature cycles including soak	No significant changes in power, spectral, and V-I-P characteristics
Shake tests (II) (June 2010)	X,Y,Z 14g spread spectrum shake (GEVS Vehicle)	No significant changes in power, spectral, and V-I-P characteristics
Bake tests (II) (June 2010)	Thermal Vac 10 ⁻⁶ tor 23 Temperature cycles including soak	No significant changes in power, spectral, and V-I-P characteristics

Modular Gravitational Reference Sensor

MGRS

MGRS Constellation For Scientific Experiments and Space Time-Position Navigation

MGRS is the next generation space gravitational reference sensor

Sun, Allen, Buchman, DeBra, Byer, LISA 5th Symposium ESTEC 2004, CQG (22) 2005 S287-S296

MGRS Small Satellite Series

UV LED is the First Mission

UV LED Satellite Payload Design Evolution

- 2005 Experiment
- 2006 Design
 - Geared to nanosat (Cube Sat)
 - Payload $9 \times 9 \times 18 \text{ cm}^3 = 1458 \text{ cm}^3$
- 2009 Design
 - Resized to allow COTS parts
 - Reshaped to hexagon for MGRS constellation configuration
- 2010 Design
 - KACST larger satellite allowing more UV LED testing
 - Full charge management system
 - Total payload dimension $30 \times 30 \times 20 \text{ cm}^3 = 18,000 \text{ cm}^3$

UV LED Main Payload

Option 1:

Overall Dimensions (mm) (270x190x138)

4 Boards (182x138)

4 Flexible Boards (30x 84.77)

2 Boards (65x80)

UV LED Optical Configuration and Modeling

UV LED AC Charge Management Experiment

UV LED Electronics

UV LED AC Charge Management Works in the Spherical Proof Mass, Large Gap Configuration

Single LED driven at 6.4mA ($\sim 10 \mu\text{W}$), 3.0V_{pp} bias, 100Hz

UV LED Schedule and Program

- **Launch Date: ~ July 1, 2012**
- **Payload completion: September 2011**
- **Ames, KACST, Stanford team working together until mission completion**
 - Integrated mission team
 - No middle hand over from engineering model to flight model
 - Expert review instead of program review
- **The first in MGRS Series and STAR Series**
 - Demonstration a key MGRS/LISA technology
 - STAR series risk mitigation
 - DECIGO collaboration

UV LED Satellite Work Breakdown Structure

Conclusions and Outlook

- **AlGaN UV LED and Photodiodes**
 - Extreme radiation hardness
 - Environmental robustness
 - Long operation lifetime
- **UV LED AC charge management**
 - Cubic PM GRS structure
 - Spherical MGRS structure
- **UV LED Satellite**
 - Successful payload design and demonstration
 - Launch in 2nd half 2012
- **Outlook**
 - The first MGRS small satellite series
 - AlGaN imaging devices and system
- **AlGaN optoelectronic devices have broad impacts to**
 - Space exploration
 - High energy density physics

This work was done by National Security Technologies, LLC, is under Contract No. DE-AC52-06NA25946 with the U.S. Department of Energy. DOE/NV/25946--1221

CLEO_2011_Sun.ppt 40