A HOT ELECTRONS-BASED WIDE SPECTRUM ON-ORBIT OPTICAL CALIBRATION SOURCE

David Starikov, Igor Berichev, Nasr Medelci, Esther Kim, Ye Wang, and Abdelhak Bensaoula
Space Vacuum Epitaxy Center, University of Houston,
SR1, R.724, 4800 Calhoun, Houston, TX 77204,
(713) 743-3621, fax (713) 747-7724, e-mail: bens@jetson.uh.edu

Abstract

Presently, no optical solid-state sources are available for the entire spectral range of NUV-VIS-NIR. Lamps still used for optical calibration are heavy and thermally and mechanically unstable, consume high electrical power, and have a short lifetime. Recently developed silicon carbide (SiC) based pre-breakdown light emitting diodes (LEDs) have numerous advantages over the hot filament lamps, including lack of current dependence, similarity to the solar spectrum, high thermal and temporal stability, mechanical and radiation strength, long lifetime, and miniature size. Unfortunately, the UV part of the optical emission created in the Al-SiC LED barrier is absorbed by the bulk silicon carbide wafer. Pre-breakdown electroluminescence devices from GaN films grown on sapphire offer a new approach to developing wide spectrum optical calibration sources. In contrast to SiC, GaN-based devices should exhibit a higher efficiency and a significant extension of the optical emission spectrum into the UV region. The nitride group at UH/SVEC has recently demonstrated GaN thin films with excellent surface morphology, good optical and electrical characteristics. In this paper we will describe our preliminary results from pre-breakdown electroluminescence in Schottky barrier diode structures and discuss their employment in highly stable and compact optical calibration sources for space applications.

INTRODUCTION

The problem of replacing vacuum-tube electronic devices with solid-state, semiconductor-based structures is completely solved for diodes, triodes, pentodes, and photoelements. However, it is still an open issue for light sources based on injective LEDs, LCDs, luminescent displays, and p-n- junction based semiconductor lasers (Kaplan 1991). These solid-state emission sources have successfully replaced vacuum-tube devices for indicator lights and communication purposes. There is still a need for additional solid state light sources for other types of applications. Included among these applications are light sources that can be used for calibration of on-orbit optical sensing systems working in the solar-similar spectral range. Filament lamps are commonly used as wide spectrum light emitting sources for calibration of sensing systems (Electro-Lite 1993). Although they provide a high optical output, their employment for orbital calibration purposes in the solar related spectral range is limited (FIGURE 1). Filament lamps are large and lack mechanical stability. In addition, the spectral output of a filament lamp depends very strongly on the temperature of the filament. The arc lamps (Optical Radiation 1992) sometimes used for wide spectrum range calibration have similar deficiencies. Commercially produced injective LEDs and semiconductor lasers can also be used in spectro-photometry where a wide spectrum range is not needed. For calibration in a wide spectrum range, a combination of injective LEDs with varying wavelengths can be used (ABB HAFO 1992 and Knight Optical 1994). However, in this case, it is necessary to apply interference filters since the superposition does not fill the entire range. In addition, the spectrum of injective LEDs is sensitive to the applied voltage and temperature, and the lifetime of the p-n-junctions is relatively short.

As alternative sources, pre-breakdown LEDs have numerous advantages over lamp sources and injective LEDs- including lack of current dependence, similarity to the solar radiation spectrum, high thermal and temporal stability, and miniature size. The photoelectric signal on the photosensor produced by such a source can be made high enough for high quality data acquisition since the signal selection and amplification can be improved by operating the LEDs in a pulse mode.

CP420, *Space Technology and Applications International Forum-1998*
edited by Mohamed S. El-Genk
DOE CONF-980103 © 1998 The American Institute of Physics 1-56396-747-2/98/$10.00

Downloaded 17 Jan 2011 to 159.226.100.225. Redistribution subject to AIP license or copyright; see http://proceedings.aip.org/about/rights_permissions

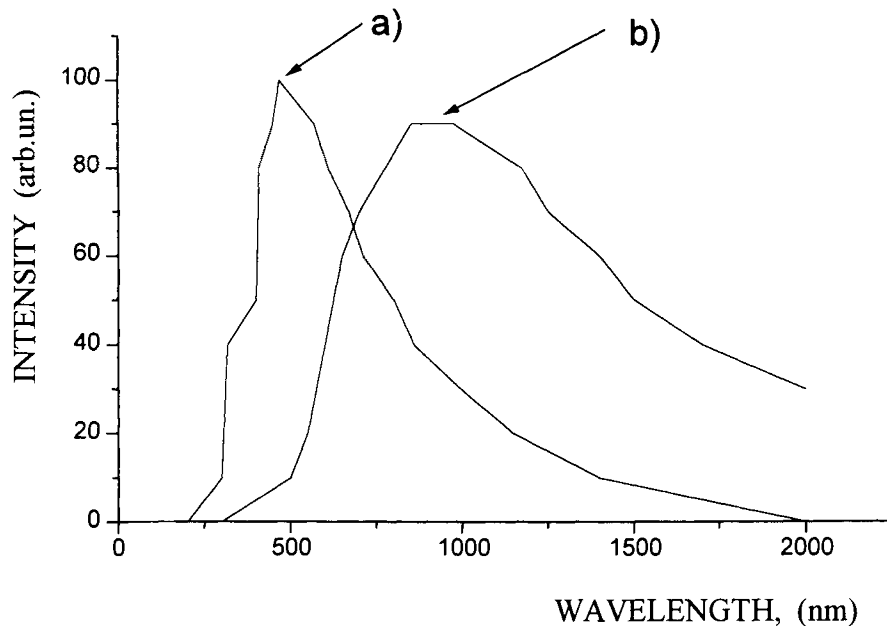


FIGURE 1. Spectra of: a) Solar Radiation above the Atmosphere (AM0), b) Spectrum from a Tungsten Filament Lamp.

PRE-BREAKDOWN ELECTROLUMINESCENCE IN REVERSE BIASED DIODE STRUCTURES

The performance of pre-breakdown LEDs is based on excitation of high energy charge carriers by a strong electric field localized in metal-semiconductor junctions and intra-band transitions that follow (Verestchagin 1990). The reverse bias creates a strong electric field at the junction making tunneling and collision processes possible. Ionization of the base material atoms, a result of electron tunneling, occurs at electric fields of 10^6 - 10^7 V/cm (transition 2 on FIGURE 2). Free charge carriers accelerated by the high electric field (transition 1) can gain a high enough energy to excite or ionize the doping or base material atoms. Due to interactions with lattice defects created by atom oscillations, the carriers lose some of the energy gained from the electric field. If the energy loss between collisions is lower then the energy gained, the electron's kinetic energy becomes greater than the bandgap, and transitions 3-6 are possible. New carriers created during the avalanche ionization, as well as the initial electrons, can be accelerated again if the field distribution is large enough. The emission spectrum of reverse-biased diode structures (FIGURE 3) in general consists of a broad band that extends to energies $h\nu > DE$, and narrow bands, with an energy of $h\nu \leq DE$, that have higher intensities at low temperatures. These narrow bands are usually present in the spectrum of the forward biased p-n-junction and are produced by recombination of the carriers through local doping levels or by band-to-band recombination of carriers having low kinetic energy. The greater the applied voltage, the higher the level of the short-wavelength emission (e.g. this part of the spectrum is produced by hot electron transitions). Measurements on GaP devices show that the quantum yield in the broad band is approximately $\sim 10^{-4}$ and is governed by the electron temperature rather than the lattice temperature. In general, the wide spectrum emission results from two processes: recombination of fast and slow electrons and holes, and transitions inside the valence and conduction zones. The mechanism of indirect transitions inside the band gap with energy transfer to a photon and the impulse transfer to an ion explains the wide spectrum shape similarity for semiconductors with different crystal structures and energy band diagrams.

Downloaded 17 Jan 2011 to 159.226.100.225. Redistribution subject to AIP license or copyright; see http://proceedings.aip.org/about/rights_permissions

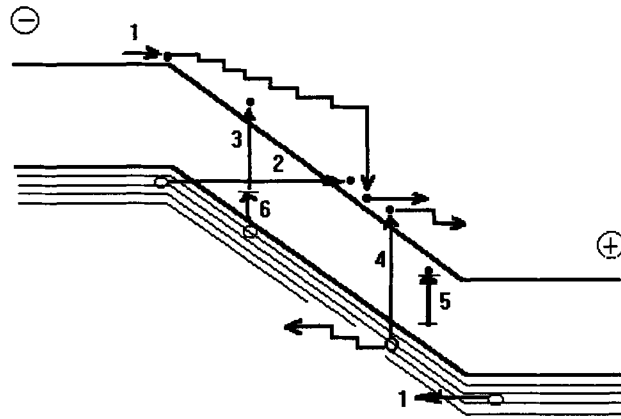


FIGURE 2. Possible Transitions Occurring in a Reverse Biased Diode Structure under the Strong Electric Field.

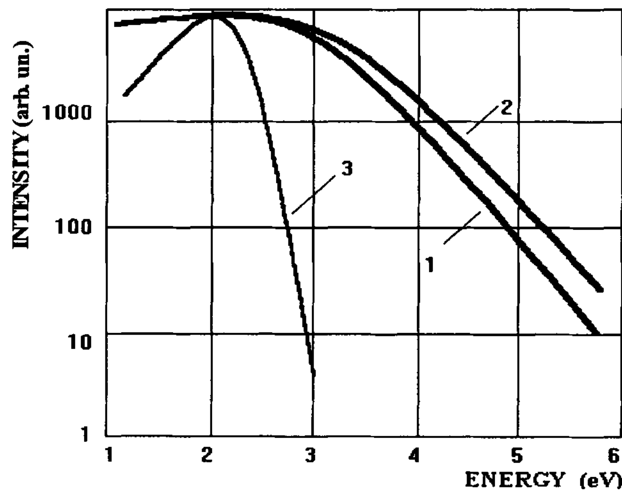


FIGURE 3. Emission Spectra from P-N- Junction in Silicon Carbide (Holuyanov 1966): 1, 2 - at a Reverse Bias (curve 2 Corresponds to a Higher Applied Voltage), 3 - at a Forward Bias.

Real p-n-junctions are always unhomogeneous due to doping and defects concentration fluctuations. As a result, the avalanche process at the applied voltage does not begin across the entire contact area, but usually in small areas (micro-plasmas) that determine the current through the junction. As in p-n-junctions, a strong electric field can be realized in reverse biased barriers formed by semiconductors and metal electrodes (Schottky barriers). Schottky barriers allow for more uniform current distribution through the contact area providing higher device stability. In addition, metal-semiconductor junctions are less thermally sensitive than p-n-junctions.

SILICON CARBIDE BASED SCHOTTKY BARRIER PRE-BREAKDOWN LIGHT EMITTING DIODES

The investigation of various metals for silicon carbide Schottky barriers formation is required to allow for a reproducible device performance and fabrication process (Kosyachenko 1986). The correlation between the fundamental material properties and Schottky barrier parameters are given in TABLE 1. Previous experimental work shows that Al, Ti, Cr, Ni, Au, and Pt are the good candidates to form metal-

Downloaded 17 Jan 2011 to 159.226.100.225. Redistribution subject to AIP license or copyright; see http://proceedings.aip.org/about/rights_permissions

TABLE 1. Correlation between Metal Work Functions and Barrier Height Potential on SiC.

Material	Work Function, φ (eV)	Barrier Height, $\Delta\varphi$ (eV)
Ti	3.9	0.65
Al	4.06 - 4.28	0.2
Cr	4.5	0.6
Ni	5.15 - 5.35	0.9
Au	5.1 - 5.47	1.0
Pt	5.65 - 5.7	1.1

semiconductor Schottky structures on silicon carbide. Silicon carbide-based wide spectrum pre-breakdown light emitting diodes have recently been developed through a NASA SBIR Phase I project. The device structure is a Al-SiC Schottky barrier and the pre-breakdown electroluminescence produced by this reverse biased structure occurs at the metal-6H-n-SiC contact area. These devices have many advantages over filament lamps and injective LEDs that are commonly used as optical calibration sources in various optical instruments and optoelectronic systems.These advantages include high thermal and temporal stability, mechanical strength, radiation resistance, miniature size, and unique spectral properties. The totally unpolarized (Kabanova 1986) radiation is relatively insensitive to current and temperature. The LEDs operation is possible in both high frequency and continuous modes making them superior for on-orbit systems as well as long term missions.

The spectrum of these LEDs is quite similar to solar radiation at ground level (AM1). The UV part of the emission created in the barrier is in this case absorbed by the bulk silicon carbide wafer which has a bandgap of 3.1 eV. This energy corresponds to a cut off wavelength of 0.4 μ which is the short wavelength limit for the devices described in FIGURE 4. Reliable UV transparent Schottky barrier contacts on SiC have yet to be developed. Experimental structures employing semitransparent gold and ITO films were evaluated but were found to be unstable and yielded non-reproducible data.

PROSPECTS FOR THE DEVELOPMENT OF CALIBRATION SOURCES BASED ON GaN

Employment of pre-breakdown electroluminescence using GaN thin films deposited on sapphire substrates is a new approach to developing wide spectrum optical emission sources. The utilization of these films in pre-breakdown device structures should permit emitters with a higher efficiency, a significant extension of the optical emission spectrum into the UV region, and a lower device cost. These unique features are possible due to the wider GaN bandgap, the use of thinner epi-layers that can be precisely controlled by the epitaxial growth, and the ability to release the optical emission through a perfectly UV-VIS-IR-transparent material - sapphire. Since GaN has a bandgap of 3.4 eV, we expect the emission spectrum to extend from below 200 nm to up to a minimum of 2500 nm and have a maximum at about 420 nm.

We have already demonstrated the growth of GaN films on sapphire by solid and gas source molecular beam epitaxy (MBE) methods (Kim 1997). These methods have allowed the growth of high quality materials on sapphire at costs that are below those of SiC bulk materials. For both deposition processes a 200 Å thick buffer layer is first grown at a substrate temperature of 823 K. This is followed by the active layer deposition at a substrate temperature of 1073-1123 K. These films exhibit excellent electrical and optical properties (FIGURE 5). For this project films with n-type conductivity and a doping concentration of $\sim 5 \times 10^{18}$ cm^{-3} were deposited. The work function of GaN is 4.1 eV. Therefore, any metal with a work function equal or lower than that of GaN should form an ohmic contact to n-type material, and any metal with higher work function should form a rectifying contact to n-type GaN. Au and Ti form rectifying contacts which become ohmic after oven annealing (Pearton 1997). For rectifying contacts Cr, Ni, Pt, and Pd (Wang 1996) are the most promising candidates. Thus, pre-breakdown electroluminescence Schottky barrier diode structures were prepared by e-beam deposition of Ti on n-type GaN films grown on sapphire. While pre-breakdown emission (FIGURE 6) has been observed from these devices, we have yet to characterize their spectral distribution.

Downloaded 17 Jan 2011 to 159.226.100.225. Redistribution subject to AIP license or copyright; see http://proceedings.aip.org/about/rights_permissions

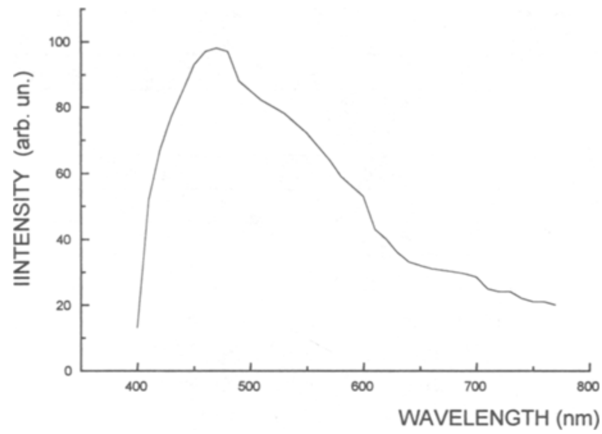
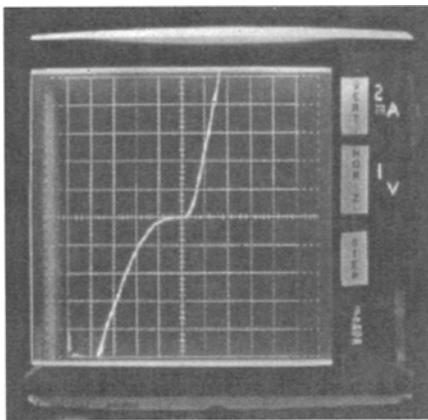
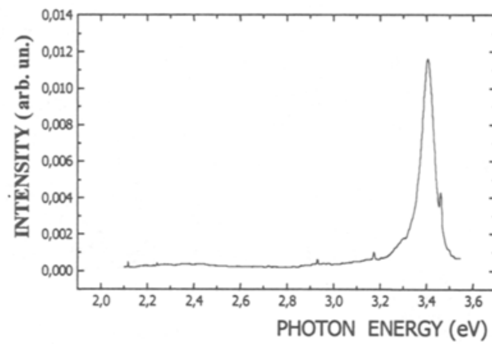


FIGURE 4. Spectrum of a SiC-Based LED. The UV Part is Absorbed in the Bulk SiC.





a) Typical Diode I-V curve of the GaN-Based Schottky Barrier Structure.

b) Photoluminescence from GaN Films Grown on Sapphire.

FIGURE 5. Semiconductor Properties of GaN Films Grown on Sapphire.

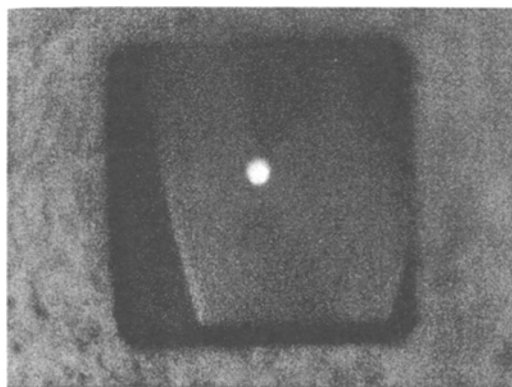


FIGURE 6. Pre-Breakdown Emission from Ti-GaN Schottky Barrier Structures.

Downloaded 17 Jan 2011 to 159.226.100.225. Redistribution subject to AIP license or copyright; see http://proceedings.aip.org/about/rights_permissions

We expect, however, that the intrinsically high mechanical, thermal, and radiation strength of the substrate and epilayers will allow for these devices to be successfully employed as on-orbit AM0-similar calibration sources.

Acknowledgment

This work is supported by funds from a NASA cooperative agreement, # NCC8-127, to SVEC. We would like to acknowledge support from U. S. Air Force SBIR contact # F33615-97-C-1035 to Ionwerks monitored by Dr. J. E. VanNostrand.

References

ABB HAFO (1992) "Broad Spectrum LED" Advertisement, in *Photonic Spectra*, 178.

Electro-Lite (1993) "UV Light System" Advertisement, in *Photonic Spectra*, 162.

Holuyanov G. F. (1961) "About the Emission at Breakdown of Silicon Carbide P-N- Junctions", in *Solid State Physics*, USSR , 3:3314 -3316.

Kabanova I. S., Kosyachenko L. A., Malimon I. V, and Starikov D. I. (1986) "Wide-Bandwidth Semiconductor Sources of Depolarized Emission," in *Photometry and its Meteorological Applications VI, All-Union Scientific Conference*, Conf. Proc., Moscow, 1:113.

Kaplan H. (1992) "Evolving Smart Calibration Systems," in *Photonic Spectra*, 170.

Kaplan H. (1991) "Bright Prospects for Brighter LEDs," in *Photonic Spectra*, 64.

Kim E., Berishev I.,Bensaoula A., Waters K., Shultz A. (1997) "A Comparative Study of GaN Growth with MBE, GSMBE and CBE Using in-situ Mass Spectroscopy of Recoiled Ions and RHEED," in *Proc. Of Texas chapter AVS Symposium on Electronic Materials, Processing, and Characterization.*

Knight Optical (1994) "UV-VIS Light Sources" Advertisement, in *Photonic Spectra*, 152.

Kosyachenko L., Starikov D, and Sklyarchuk V. (1986) "Influence of Metal's Nature and Semiconductor Surface Preparation on the Properties of Silicon Carbide Contact with Metal," in *Electronic Technique, Ser. 2., Semiconductor Devices,* USSR, 5:106.

Optical Radiation (1992) "Xenon Fiber Optics Source" Advertisement, in *Photonic Spectra*, 178.

Pearton S. J. H., Ren A.F., Shul R. J. and Zolper J.C. (1997) "Device Processing of Wide Bandgap Semiconductors - Challenges and Directions," in *Electrochemical Society Proceedings*, 97:1.

Verestchagin I. K., Kovalev B. A., Kosyachenko L.A., and Kokin C. M. (1990) *in Electroluminescence Sources of Light*, Energoatomizdat, Moscow, 1:22-28.

Wang L. and Nathan M.I. (1996) "High Height GaN Schottky diodes: Pt/GaN and Pd/GaN", in *Appl. Phys. Lett.* 68:9.

Downloaded 17 Jan 2011 to 159.226.100.225. Redistribution subject to AIP license or copyright; see http://proceedings.aip.org/about/rights_permissions