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13. ABSTRACT (Maximum 200 words) Abstract: This is the final report for an AASERT grant funding John Torvik, Ph.D. The report consists of the Ph.D. dissertation that came from this research. The work addresses the behavior of the rare earth erbium (Er) doped into GaN, with co-dopants oxygen and fluorine. The Er luminescence properties were studied versus temperature (10K, 77K, and up to room temperature), annealing treatment (number of anneals, duration, and temperature), co-dopant concentration (over three orders of magnitude), and the Er density. Co-dopants were essential to the successful detection of luminescence in the 1550 nm ($^4I_{13/2} - ^4I_{15/2}$) band. An annealing treatment following the ion implantation of the Er and co-dopant ions was also required. Photo-luminescence lifetime data versus Er density, pump wavelength, and temperature are presented. Photo-luminescence excitation (PLE) spectroscopy over the wavelength range 770-1010 nm using a tunable Ti:Sapphire laser, at 77K and room temperature, showed the usual thermal quenching for most pump wavelengths, but not all. A metal-insulator-n-type diode structure also exhibited 1550 nm luminescence. Cathodo-luminescence measurements showed weak 980 nm luminescence while the PLE measurements did not. A list of publications and presentations related to this work is also included.					
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**Final Report: AASERT Program funding Dr. John T. Torvik
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Luminescence Properties of Rare Earth Doped Semiconductors**

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Introduction

This is the final report for an AASERT grant. The report is a copy of the Ph.D. dissertation that resulted from this research. There is also an appendix listing the publications and presentations that resulted from this work. The work addresses the behavior of the rare earth erbium (Er) ion implanted into GaN, with co-dopants oxygen and fluorine. We are pleased to acknowledge our collaborator, Dr. F. Namavar of Spire Corporation for his ion implantation and characterization of the GaN material.

The GaN:Er luminescence properties were studied versus temperature (10K, 77K, and up to room temperature), annealing treatment (number of anneals, duration, and temperature), co-dopant concentration (over three orders of magnitude), and the Er density. Co-dopants (oxygen or fluorine) were essential to the successful detection of luminescence in the 1550 nm ($^4I_{13/2} - ^4I_{15/2}$) band. An annealing treatment following the ion implantation of the Er and co-dopant ions was also required. Photoluminescence lifetime data versus Er density, pump wavelength, and temperature are presented. The GaN:Er,O material was studied with photoluminescence excitation (PLE) spectroscopy. The signal was at the peak luminescence wavelength of 1539 nm and the pump scanned over the wavelength range 770-1010 nm using a tunable Ti:Sapphire laser. Measurements were performed at 77K and at room temperature. The results showed the usual thermal quenching for most pump wavelengths, but not all. A GaN:Er metal-insulator-n-type (MIN) diode structure also exhibited 1550 nm luminescence. Cathodo-luminescence measurements showed weak 980 nm luminescence while the PLE measurements did not.

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Appendix I. Publications and Presentations

This appendix lists the papers and presentations by the investigators concerning this research. It also includes the AASERT student's Ph.D. thesis title and some works submitted to journals.

Journal and Published Conference Papers

1. J.T. Torvik, C.H. Qiu, R.J. Feuerstein, J.I. Pankove, F. Namavar, "Photo-, cathodo-, and electro-luminescence from erbium and oxygen co-implanted GaN," J. Appl. Phys. (May 1997).
2. J.T. Torvik, R.J. Feuerstein, J.I. Pankove, C.H. Qiu, F. Namavar, "Electro-luminescence from erbium and oxygen coimplanted GaN," Appl. Phys. Lett., 69(14), pp. 2098-2100 (1996).
3. J.T. Torvik, R.J. Feuerstein, J.I. Pankove, F. Namavar, "Annealing study of erbium and oxygen implanted gallium nitride," Mat'ls Res. Soc. Symp. Vol. 422, pp. 199-204, MRS Pittsburgh, PA (1996). Ed.'s S. Coffa, A. Polman, R.N. Schwartz.
4. J.T. Torvik, C.H. Qiu, R.J. Feuerstein, J.I. Pankove, F. Namavar, "Luminescence at 1539 nm from Er and Oxygen implanted GaN." 1996 Conf. on Optoelectronic and Microelectronic Materials and Devices (COMMAD 96), Dec 9-11, 1996, Canberra, Australia.
5. C.H. Qiu, M.W. Leksono, J. Torvik, R.J. Feuerstein, J.I. Pankove, F. Namavar, "Cathodo-luminescence study of Er and Oxygen co-implanted Gallium Nitride thin films on Sapphire substrates," Appl. Phys. Lett. 66(5), pp. 564 (1995).
6. J.I. Pankove, R.J. Feuerstein, "Electrically Pumped Rare Earth Doped Semiconductor Lasers," Mat'ls Res. Soc. Symp. Vol. 301, pp. 287-292, MRS Pittsburgh, PA (1993). Ed.'s G.S. Pomrenke, P.B. Klein, D.W. Langer.

Ph.D. Dissertation

Dr. John T. Torvik, "The Doping and Characterization of Erbium in Gallium Nitride."

Conference, Workshop and Other Presentations

(by R.J. Feuerstein)

1. "Rare Earth doped semiconductors for interconnects," at the ISHM/IEPS Advanced Technology Workshop on Optoelectronics, Ojai, CA, invited paper, Feb. 21, 1995.
2. "Luminescence in Rare Earth Doped Semiconductors," Paper to URSI meeting, Boulder, CO, invited paper, Paper D1-3, Jan. 3, 1995.
3. "Cathodoluminescence in Erbium doped Gallium Nitride," at the European Quantum Electr. Conf., Amsterdam, Netherlands, August 28 - Sept. 2, 1994.
4. "Luminescence in Er doped GaN," at the Rare Earth Doped Optoelectronic Materials Workshop, Hughes Laboratories, Malibu, CA, June 16-17, 1994 .
5. "Erbium Doped Silicon for Optical Sources and Amplifiers," at the URSI meeting, Boulder, CO., Jan. 1994.
6. "Luminescence in Rare Earth Doped Semiconductors," at the National Institute of Standards and Technology, Boulder, CO., Nov. 12, 1993.
7. "Erbium Doped Silicon for Lasers and Amplifiers," to the Microwave Optics Seminar, Univ. of CO, Boulder, CO, March 2, 1993.

Submitted Works

1. J.T. Torvik, R.J. Feuerstein, C.H. Qiu, J.I. Pankove, F. Namavar, Photoluminescence excitation measurements on erbium implanted GaN," Submitted to J. Appl. Phys. April 1997.
2. J.T. Torvik, R.J. Feuerstein, W.A. Melton, J.I. Pankove, "Luminescence in Rare Earth Doped Semiconductors," Applied Physics Reviews, (currently implementing reviewers comments).