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EDUCATION

Ph.D., Physics, 1969, University of California, Riverside
M.A., Physics, 1965, University of California, Riverside
B.A., Physics, 1963, Pepperdine University, Los Angeles

ACADEMIC APPOINTMENTS

9/84 - Present Professor of Physics, Univ. of Missouri, Columbia, MO
9/75 - 8/83 Assoc. Prof. of Physics, Univ. of Missouri, Columbia, MO
9/69 - 8/75 Assist. Prof. of Physics, Univ. of Missouri, Columbia, MO

ADMINISTRATIVE APPOINTMENTS

9/98 – 8/04 Chair, Department of Physics and Astronomy
4/96 - 9/96 Chief Operating Officer, Missouri University Research Reactor
9/83 - 8/92 Chair, Department of Physics and Astronomy
1/01 – Present Chief Scientist, MOXtronics, Inc., Columbia, MO

PROFESSIONAL SOCIETY MEMBERSHIPS

American Physical Society
Materials Research Society
Optical Society of America

HONORS AND AWARDS

Faculty Recognition Award, Science Teachers of Missouri, 2003
University of Missouri Presidential Faculty Entrepreneur Award 2002
University of Missouri Faculty Development Award, 1992-93
Faculty Award, University of Missouri Alumni Association, 1990 Purple Chalk Teaching Award, Arts and Science Student Association, 1989
Ames Laboratory Summer Fellowship, 1974
Summer Research Fellowships, University of Missouri, 1970, 1971, 1972
Outstanding Graduating Senior, Pepperdine University Alumni Association, 1963

RESEARCH INTERESTS

I. Growth and development of zinc oxide wide bandgap semiconductor material for fabrication of LEDs, LDs, visible and solar blind UV detectors.

II. Production of gold and silver nanoparticles for biomedical and other applications.

Overview of ZnO work:

The optical properties of zinc oxide (ZnO) are being studied for potential use in semiconductor devices, in particular for photonic light emitting devices such as light emitting diodes (LEDs), laser diodes (LDs) and photonic detectors such as photodiodes. The energy band gap of ZnO is approximately 3.3 electron volts (eV) at room temperature, corresponding to a wavelength of approximately 376 nanometer (nm) for an emitted photon of this energy. Light emission has been demonstrated from ZnO LEDs using p-type and n-type materials to form a diode. ZnO has also been used to fabricate a UV photodetector and a field effect transistor (FET).

ZnO has several important properties that make it a promising semiconductor material for optoelectronic devices and applications. ZnO has a large exciton binding energy, 60 meV, compared with 26 meV for GaN and 20 meV for ZnSe. The large exciton binding energy for ZnO indicates promise for fabrication of ZnO-based devices that would possess bright coherent emission/detection capabilities at room and elevated temperatures. ZnO has a very high breakdown electric field, estimated to be about 2×10^6 V/cm (> two times the GaAs breakdown field), indicating thereby that high operation voltages could be applied to ZnO-based devices for high power and gain. ZnO also has a saturation velocity of 3.2×10^7 cm/sec at room temperature, which is larger than the values for gallium nitride (GaN), silicon carbide (SiC), or gallium arsenide (GaAs). Such a large saturation velocity indicates that ZnO-based devices would be better for high frequency applications than ones made with these other materials.

Still further, ZnO is exceptionally resistant to radiation damage by high energy radiation. Common phenomena in semiconductors caused by high-energy radiation are the creation of deep centers within the forbidden band as well as radiation-generated carriers. These effects significantly affect device sensitivity, response time, and read-out noise. Therefore, radiation hardness is very important as a device parameter for operation in harsh environments such as in space and within nuclear reactors.

From the perspective of material radiation hardness, ZnO is much better suited for space operation than other wide bandgap semiconductors. For example, ZnO is about 100 times more resistant than is GaN against damage by high-energy radiation from electrons or protons.

ZnO also has a high melting temperature, near 2000°C, providing possibilities for high temperature treatments in post-growth processes such as annealing and baking during device fabrication, as well as for applications in high temperature environments.

Large-area ZnO single crystal wafers (up to 50 mm diameter) are commercially available. It is possible to grow homo-epitaxial ZnO-based devices that have low dislocation densities. Homo-epitaxial ZnO growth on ZnO substrates will alleviate many problems associated with hetero-epitaxial GaN growth on sapphire, such as stress and thermal expansion problems due to the lattice mismatch.

ZnO has a shallow acceptor level, 129 meV, compared with 215 meV for GaN. The low value for the acceptor level means that p-type dopants in ZnO are more easily activated and thereby help generate a higher hole concentration in ZnO than the corresponding hole concentration in GaN for the same dopant concentration in each material. ZnO based devices can be fabricated by a wet-chemical etch process. These properties make ZnO a most attractive material for development of near- to far-UV detectors, LEDs, LDs, FETs, and other optoelectronic devices.

Yungryel Ryu, Taeseok Lee and Henry White are co-founder members of MOXtronics, Inc., Columbia, MO. MOX has developed a Hybrid Beam Deposition (HBD) process that enables, among other aspects, the growing of p-type ZnO using an external As-molecular beam to incorporate As-dopant into a ZnO film. The HBD process for producing As-doped p-type ZnO films can be used to precisely control the doping level. In particular, hole carrier concentrations sufficiently high for semiconductor layers. The thermal binding energy of the As-acceptor (E_A^{th-b}) is 129 meV, as derived from temperature-dependent Hall Effect measurements. The PL spectra reveal two different acceptor levels (E_A^{opt-b}), located at 115 and 164 meV, respectively, above the maximum of the ZnO valence band, and also show the binding energy of the exciton to the As-acceptor (EAXb) is about 12 meV. The quality of p-type ZnO:As layers grown by HBD are sufficiently high for device fabrication.

MOX has developed three ZnO based devices; namely, a UV detector, a FET, and a LED.

ZnO Publications:

"Optical and Structural Properties of ZnO Films Deposited on GaAs by Pulsed Laser Deposition," Y.R. Ryu, S. Zhu, J.D. Budai, H.R. Chandrasekhar, P.F. Miceli, and H.W. White, J. Appl. Phys., **88**, 201-4 (2000).

"Comparative Study of Textured and Epitaxial ZnO Films," Y.R. Ryu, S. Zhu, J.M. Wrobel, H.M. Jeong, P.F. Miceli, and H.W. White, J. Cryst. Growth **216**, 326-329 (2000).

"Synthesis of P-Type ZnO Films," Y.R. Ryu, S. Zhu, D.C. Look, J.M. Wrobel, H.M. Jeong, and H.W. White, J. Cryst. Growth **216**, 330-34 (2000).

"Fabrication of Homostructural ZnO P-N Junctions," Y.R. Ryu, W.J. Kim, and H.W. White, J. Cryst. Growth, **219**, 419-22 (2000).

"Properties of Arsenic (As) Doped p-type ZnO grown by Hybrid Beam Deposition," Y.R. Ryu, T.S. Lee and H.W. White, Appl. Phys. Lett. **83**, 87-89 (2003).

"Fabrication of Homostructural ZnO p-n Junctions and Ohmic Contacts to Arsenic-doped p-type ZnO Y.R. Ryu," T.S. Lee, J.H. Leem and H.W. White, Appl. Phys. Lett. **83**, 4032-34 (2003).

"A Technique of Hybrid Beam Deposition for Synthesis of ZnO and Other Metal Oxides", Y. R. Ryu, T. S. Lee, and H. W. White, J. Crystal Growth **261**, 502-07 (2004).

"ZnO Devices: Photodiodes and P-type Field-Effect Transistors," Y. R. Ryu, J. A. Lubguban, and T. S. Lee, H. W. White, Y. S. Park, C. J. Youn. Appl. Phys. Lett. **87**, 153504-06 (2005).

"Wide-Band Gap Oxide Alloy – BeZnO," Y. R. Ryu, T. S. Lee, J. A. Lubguban, A. Corman, H. W. White, J. H. Leem, M. S. Han, Y.S. Park, C. J. Youn, and W. J. Kim. Appl. Phys. Lett. **88**, 052103-04 (2006).

"Next generation of oxide photonic devices: ZnO-based ultraviolet light emitting diodes," Y. R. Ryu, T.S. Lee, J. A. Lubguban, H. W. White, B.J. Kim, Y. S. Park, and C. J. Youn, Appl. Phys. Lett. 88(24) 1108 (2006).

"ZnO-based LEDs begin to show full –color potential," Henry White and Yung Ryu, Compound Semiconductor, (to appear, August 2006).