ZnO-Based Oxide Semiconductors: A Material Platform for High Power Room Temperature THz QCLs

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Biography

Dr. Mehdi Anwar currently serves as a Full Professor in the Electrical and Computer Engineering department. He is the Director of the NSF funded Industry University Cooperative Research Center. He has also served as the Associate Dean for Research & Graduate Education of the School of Engineering, University of Connecticut from June 2006 till May 2009. He served as the founding Director of the Department of Homeland Security Center of Excellence from June 2007 till May 2009. Moreover, he was the interim Director of the Connecticut Global Fuel Cell Center serving from June 2007 till January 2009. He served as the interim Department Head of ECE from June 1999 – August 2001.

Dr. Anwar is currently working on (a) ZnO Nanowire based UV detection and energy harvesting, (b) III-Nitrides and Oxide Semiconductor -based high power and high temperature quantum cascade lasers and (c) RF Oxide Semiconductor HFETs. Dr. Anwar's interests include localization of one-dimensional structures, transport in semiconductor devices, impurity diagnostics in quantum well structures, Sb-based type-II infrared detectors, noise in semiconductor devices, power performance of GaN-based HFETs and circuits. He has developed measurement techniques to carry out trap characterization in InP and GaN-based HEMTs and load pull setups operating at W-band while the modeling interests span a breadth of subject areas and include transport in DNA, silicon nano-wires, quantum well infrared photodetectors, stochastic quantum mechanics and noise in quantum structures. Dr. Anwar's team pioneered noise measurement in metamorphic antimony-based-compound-semiconductor (ABCS) HEMTs with quaternary buffer/barrier and ternary. His design launched AFRL to develop the first metamorphic HEMTs with an f_T around 200FGHz and F_{min} of 0.82dB at 15GHz, using a 0.15 micron gate. He has presented over 30 plenary and invited talks at national/international conferences, offered tutorials on nanosensors at Optics East, published over 180 archival journal publications and conference proceedings and co-authored four book chapters.

Dr. Anwar served as an Editor of the IEEE Transactions on Electron Devices (2001 – 2010) and serves as the conference chair of the international conference on Terahertz Physics, Devices and Systems: Advanced Applications in Industry and Defense of the SPIE Defense, Security and Sensing (2009, 2010, 2011, 2012). He has also chaired the 2006 and 2007 Terahertz Physics, Devices and Systems Conference as part of SPIE's Optics East. He serves as the Director of the NSF funded Industry University Cooperative Research Center addressing electrochemical energy conversion and storage. Dr. Anwar is an SPIE Fellow.

Abstract

The non-evasive and contactless THz imaging of obscure or hidden objects has found wide application in the security community along with the standard applications ranging from astrophysics to the inspection of integrated circuits. Most of the applications prefer high power THz sources operating at room temperature, however, the availability of such high power THz sources still remains a challenge. Using III-V material, distributed feedback Quantum Cascade Lasers (QCL) an output power of 2.4 watts have been reported. It is anticipated that the group III-nitrides may allow even higher output power at room temperature due to the rather large polar optical phonon energy, however, such experimental results are yet to be reported. $ZnO/Zn_{1-x}Mg_xO$ provides an alternative material system that may also allow high power room temperature generation of THz radiation.

We will performance parameters and discuss the merits and short comings of III-V, III-nitrides

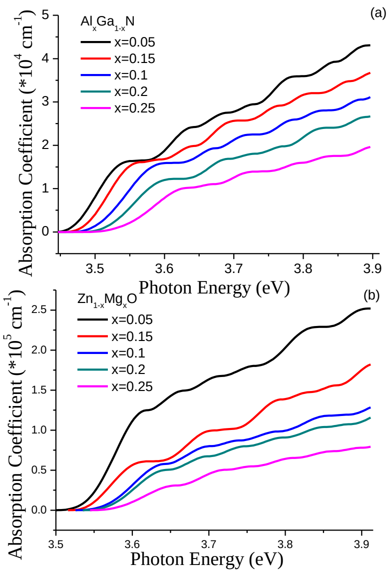

Fig. 1.Absorption coefficient as a function of photon energy (a) $GaN/Al_xGa_{1-x}N$ (b) $ZnO/Zn_{1-x}Mg_xO$.

and ZnO/ $Zn_{1-x}Mg_xO$ QCL operating at room temperature. Initial calculations demonstrate higher absorption in the ZnO/ $Zn_{1-x}Mg_xO$ ($2.6*10^5 cm^{-1}$) than in $GaN/Al_xGa_{1-x}N$ ($4.3*10^4 cm^{-1}$) heterostructures (Fig. 1). The absorption coefficient,

$$\alpha = (\pi e^2 \hbar c \mu_0 / 2.m_r^* n_r) f_{n'n} J_{n'n} * \Delta N ,$$

where the different parameters have their usual significance. The calculated results show higher absorption in the ZnO/ $Zn_{1-x}Mg_xO$ and that can be attributed to (a) a smaller average effective mass, m_r^* and (b) lower refractive index, n_r in $ZnO/Zn_{1-x}Mg_xO$ as compared to that in $GaN/Al_xGa_{1-x}N$. Besides, $Zn_{1-x}Mg_xO$ has larger matrix elements $P_{n'n}$ which results in better oscillator strength $f_{n'n}$ and consequently a higher optical gain as shown in Fig. 2. A higher THz output power of P_{ZnMgO}=3.7mW is obtained for $ZnO/Zn_{1-x}Mg_xO$ as compared to P_{AlGaN}=2.6mW for a comparably structured AlGaN/GaN QCL, both operating around 3.4 THz (Fig. 3). The calculated THz output power,

$$P_{out}(\omega) = (V m_{tot} \alpha_{M_2} c \hbar\omega / n_r \Gamma)$$

, is higher in ZnO-material system due to its smaller refractive index (n_r^{ZnMgO}=1.65, ω_{ZnMgO}= 3.63 THz , n_r^{AlGaN}=2.49, ω_{AlGaN}=3.23 THz). A comparison of Wall Plug Efficiencies ($WPE_{ZnO/ZnMgO}$=18.61%,$WPE_{GaAs/InGaAs}$=14.38%) clearly demonstrate the prospect of

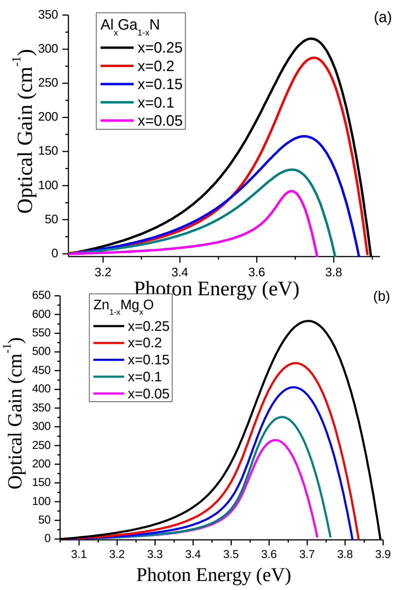

Fig. 2.Optical gain as a function of photon energy (a) $GaN/Al_xGa_{1-x}N$ (b) $ZnO/Zn_{1-x}Mg_xO$.

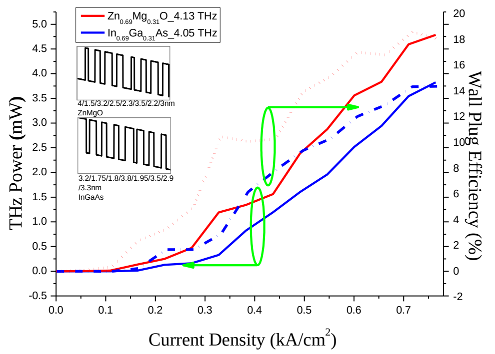

Fig. 3.Output power and WPE as a function of injection current; $ZnO/Zn_{1-x}Mg_xO$, $GaN/Al_xGa_{1-x}N$, $GaN/In_xGa_{1-x}N$ and $GaAs/In_xGa_{1-x}As$.

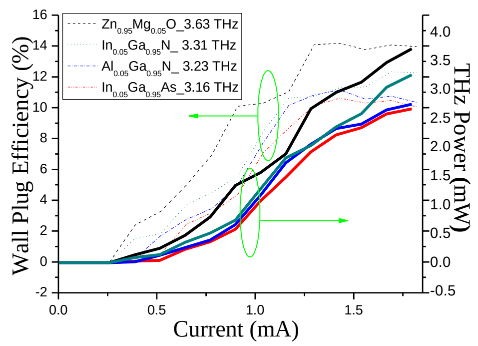

Fig. 4. Output power and WPE as a function of current density.

ZnO-based oxide semiconductors as possible material platforms for room temperature THz sources (Fig. 4). We will also present results on the MOCVD assisted growth of ZnO/ZnMgO eplilayers required for the fabrication of the Oxide Semiconductor QCLs.

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