Mid-IR Optoelectronics: Materials and Devices
Room Lecture Hall, Nielsen Hall - Session MIOMD-TuM2

Silicon Photonics

Moderator: Daniel Wasserman, University of Texas at Austin

10:30am **MIOMD-TuM2-14 GaSb-Based ICLs Grown on GaSb, GaAs and Si Substrates***, M. Fagot, D. Díaz-Thomaz, A. Gilbert, G. Kombila N'Dmengoye, Y. Rouillard, A. Baranov, J. Rodriguez, E. Tournié,* ***Laurent Cerutti,*** IES - University Montpellier, France **INVITED**

GaSb-based Interband Cascade lasers (ICLs) have emerged as the leading optoelectronic source in the 3-6µm wavelength range. Although ICLs are very attractive for various applications such as laser spectroscopy or free-space communication, the cost and size of substrates pose a significant limitation to their widespread commercialization. However, recent studies have shown that the unique band diagram of the ICLs active zone, is tolerant to mid-gap defect states induced by dislocations. Thus, the growth of ICLs on large, inexpensive, and mismatched substrates presents a viable solution for the low-cost production of high-performance mid-infrared (MIR) lasers and MIR photonic sensors on GaAs or Si-photonic integrated circuits (PIC).

In this study, we have examined the performance of ICLs designed to emit at 3.3 µm , which were grown simultaneously on GaSb, GaAs, and on-axis Si (001) substrates. The ICL structures consisted of two n-type AlSb/InAs superlattice claddings and a 5-stage interband cascade active region sandwiched between two n-type GaSb separate confinement layers. After the growth, the structures were processed into 8 µm x 2 mm laser devices and bonded epi-side up, with the bottom contact taken into the bottom cladding.

All the lasers operated in the continuous wave (CW) regime at RT and emitted around 3.3 µm. The threshold current is approximately 40 mA whereas the maximum output power decreased from 42 mW for the lasers on GaSb to 37 and 32 mW for the devices on GaAs and Si substrates, respectively. We attribute the observed decrease in the optical power to a higher voltage drop which results in overheating of the active region. The higher series resistance in these devices can be explained by poorer lateral electrical conductivity of the cladding in presence of threading misfit dislocations in the mismatched structures. These encouraging results open the way to the development of low cost ICLs and integrated photonic sensors for PIC.

11:00am **MIOMD-TuM2-17 Electrically Injected GeSn Laser on Si Substrate Operating Up to 130 K***,* ***Sudip Acharya****, S. Yu,* University of Arkansas

Germanium-tin (GeSn) semiconductors have gained significant attention over the last years as a group IV material for the development of novel Si-based optoelectronic devices. Specifically, direct band gap GeSn alloys with Sn fractions above 8% are of interest as light emitting sources in the near- and mid-infrared spectral range. In addition, GeSn epitaxy is monolithic on Si and also fully compatible with the complementary metal-oxide semiconductor (CMOS) technology, making it a promising candidate for the integrated light source on the Si platform, with advantages such as cost-effectiveness, reliability, and compactness [2]. Recently, GeSn lasers on Si substrate were demonstrated both under optical pumping and electrical injection. In this work, we report an electrically injected GeSn/SiGeSn are grown on Si substrate operating up to 130 K. Our study is mainly focused on the cap layer effect on the optical loss for lasing devices. The GeSn/SiGeSn heterostructure was grown using chemical vapor deposition (CVD) technique. The GeSn lasers devices were fabricated in ridge waveguide structures with 80 µm, 100 µm and 120 µm wide ridges. The lasing performance was investigated under pulsed conditions. The electroluminescence signal was collected through a monochromator and liquid-nitrogen-cooled InSb detector (response range 1–5.5 µm). The L-I characteristics of devices with different cavity length was studied at different temperatures. Our results suggest a promising way for enhancing the lasing performance of electrically injected GeSn laser diodes.

11:20am **MIOMD-TuM2-19 Temperature and Band Structure Dependent Properties of GeSn Double Heterostructure Lasers***,* ***Aneirin Ellis,*** University of Glasgow, UK

The development of monolithically integrated group-IV lasers remains a key challenge in realising Si-based integrated optoelectronic circuits [1]. With its direct bandgap and the possibility for wavelength tuning through strain and composition engineering, GeSn has emerged as an interesting approach. However, GeSn lasers have been primarily limited to low temperature operation. Understanding the carrier recombination behavior is therefore vital to develop improved devices with higher operating temperatures. Here, we investigate bulk $Ge_{0.89}Sn_{0.11}$ lasers grown using chemical vapor deposition [2]. In this study, high pressure, low temperature measurements are used to vary the electronic band structure for a fixed thermal carrier distribution, enabling purely band structure dependent mechanisms to be probed. Analysis of the threshold current density with pressure indicates an L-valley occupation of ~1% at 85K, determined from the fit in Fig. 1 a). Above this temperature, the fractional L-valley occupation increases strongly, indicated by a sharp rise in the threshold carrier density (assuming only mirror losses), illustrated by the red line in Fig. 1 b). This increases the pump threshold leading to device heating, increasing the L-valley occupation further and heightening free carrier absorption losses. The implications for this in terms of optimising the laser design for ambient temperature operation will be discussed.

[1] Wang, B. *et al.Light Sci Appl***10**, 232 (2021).

[2] Zhou, Y. *et al.* Optica **7**, 924-928 (2020).

11:40am **MIOMD-TuM2-21 Integrating GaSb-Based Infrared Detectors with Si Substrates via Interfacial Misfit Arrays***,* ***Trent Garrett****, J. Tenorio, M. Drake,* Boise State University*; P. Reddy, K. Mukherjee,* Stanford University*; K. Grossklaus,* Tufts University*; S. Miamon,* NetzVision LLC*; P. Simmonds,* Boise State University

With applications from night vision and aerial target acquisition, to space telescope operation, infrared (IR) detectors are of great interest to the defense and scientific communities alike. The functionality of these detectors hinges on achieving a high signal-to-noise ratio so that weak signals can still be resolved. Of the many IR detector designs, the nBn device has emerged as a leading choice. As the name suggests, nBn detectors comprise an electron-blocking barrier between *n*-type absorber and contact layers [1]. nBn-based IR detectors are typically grown on GaSb substrates, which are expensive and only widely available up to 4–6” diameter. In addition, integrating a detector grown on a GaSb substrate with the Si-based ROIC via direct bonding interconnect processing is difficult. nBn detectors produced directly on Si substrates would overcome these problems. However, this approach comes with its own set of challenges, primarily due to the large lattice mismatch between GaSb and Si. We therefore adopt the use of interfacial misfit (IMF) arrays grown by molecular beam epitaxy (MBE) to manage strain at the III-Sb/Si heterointerface. IMFs consist of the spontaneous formation of a 2D array of 90º dislocations that lie in the plane of the heterointerface. Previous studies show that thin initiation AlSb layers between the GaSb and Si are critical. GaSb deposited onto an AlSb/Si IMF heterostructure has dramatically improved material quality and lower threading dislocation density (TDD) [2]. We will discuss how choices regarding AlSb growth initiation, substrate temperature, annealing, AlSb thickness, and AlSb growth rate affect the quality of GaSb overlayers. By optimizing these MBE growth parameters, initial results suggest that we can grow GaSb layers with quality comparable to the current state-of-the-art, giving us a benchmark against which to measure further improvements. We will discuss the performance of nBn devices integrated with our optimized GaSb-on-Si buffers. Promising initial results include background limited infrared photodetection (BLIP) at 150 K, and the ability to carry out thermal imaging with a 300 K blackbody background. This work is supported by the Office of Naval Research through grant #N00014-21-1-2445 and by the National Science Foundation grant GRFP #1946726

[1] S. Maimon and G.W. Wicks, Applied Physics Letters **89**, (2006).

[2] K. Akahane, N. Yamamoto, S.-I. Gozu, and N. Ohtani, Journal of Crystal Growth **264**, 21 (2004).

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