Fabrication of $In_xGa_{1-x}N$ Laser Diodes on Copper Substrates by Laser Lift-off

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The combination of its high-temperature stability, similar crystal symmetry with the III-nitrides, and its relatively low cost has made sapphire the substrate of choice in development of III-nitride-based blue laser diodes (LDs). High-performance InGaAlN LDs have been realized on sapphire substrates with today's most advanced devices operating at room-temperature under continuous-wave conditions with lifetimes greater than 10000 hours.[1] Nevertheless, a major impediment to the development of III-nitride LDs still remains the efficient dissipation of heat generated from the active area of the device. The high thermal resistance of the sapphire substrate and the relatively high current densities combine to degrade the device performance and lifetimes due in part to excessive heating during operation. Although substrates such as silicon or copper would be more ideal, direct deposition and fabrication of III-nitride-based laser devices on these materials are either unfeasible or result in poor quality devices. A more viable means of materials integration to improve the blue laser performance is by thin film lift-off and transfer of pre-fabricated, fully functional devices from sapphire onto another host substrate. Such an approach allows integration of materials selected and pre-fabricated exclusively for optimal device performance rather than for growth compatibility.

As a demonstration of this methodology for improving III-nitride LD performance, prefabricated $In_xGa_{1-x}N$-based multiple quantum-well (MQW) LDs on sapphire substrates were successfully transferred from sapphire onto Cu substrates. The separation of the LDs from sapphire was accomplished by using a laser lift-off (LLO) process[2] in which a single 20 ns XeCl excimer laser pulse was directed through the transparent substrate. The absorption of the 308 nm radiation at a laser fluence of 600 mJ/cm^2 by the GaN at the substrate/film interface induces rapid thermal decomposition of the GaN interfacial layer. Heating the structure above the melting point of Ga (T_m=30°C) completed the separation and transfer process. Characterization of the $In_xGa_{1-x}N$ LDs before and after the sapphire substrate removal revealed no measurable degradation in device performance. The threshold current, under pulsed operation, for a 3×500 μm^2 device and the laser emission spectrum remained essentially unchanged before and after the LLO process (Figures 1 and 2). Additionally, the conductive Cu substrate permitted fabrication and operation of a vertically-arranged LD using the Cu as a back contact. Electrical measurements from such a vertically-connected LD showed enhanced I-V characteristics due in part to the removal of the laterally placed topside n-contact (Figure 3). Additional results from $In_xGa_{1-x}N$-based LDs fabricated with an epitaxial-layer overgrowth technique will also be discussed. The transfer of the $In_xGa_{1-x}N$ MQW LDs from sapphire onto Cu substrates demonstrates the efficacy of the LLO process to integrate these LDs onto virtually any substrate material.

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[1] S. Nakamura, M. Senoh, S. Nagahama, N. Iwasa, T. Yamada, T. Matushita, Y. Sugimoto, T. Kozaki, H. Umemoto, M. Sano, and K. Chocho, Jpn. J. Appl. Phys., Part 2 **37**, L627 (1998).

[2] W.S. Wong, T. Sands, and N.W. Cheung, Appl. Phys. Lett. **72**, 599 (1998).

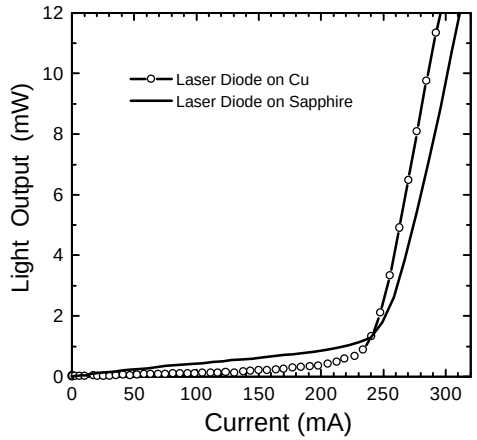

Figure 1: Light-output vs. current characteristics for a 3· 500 mm^2 device before and after LLO.

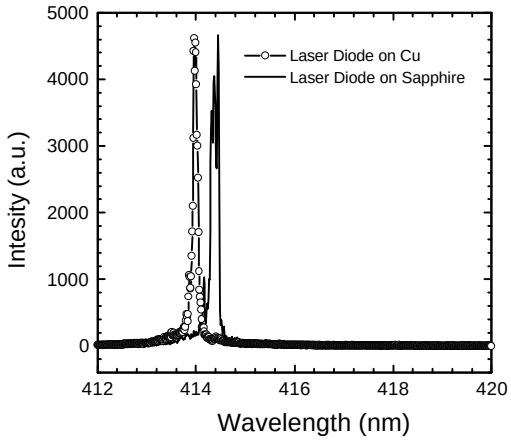

Figure 2: Room-temperature laser emission spectra for a 3· 500 mm^2 device before and after LLO.

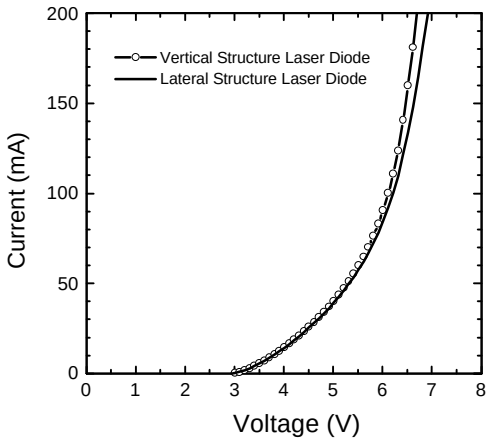

Figure 3: Improved I-V characteristics for a vertically-contacted LD on Cu in comparison to laterally-contacted LD on sapphire.