Design of High-Power near-2-µm Pumped Laser Diodes for Ho Fiber Lasers

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Holmium-doped high power fiber lasers operate at an eye-safe wavelength (λ~2.1 µm) and have been demonstrated 400 W continuous-wave powers[1]. Fiber lasers operating in this wavelength region have applications in remote sensing, free-space optical communication, and as pump sources for mid-infrared optical parametric oscillators[1]. Traditionally, the optical pumping of these Ho fiber lasers is done through a series of different pump sources at different wavelengths. A 793 nm semiconductor diode laser is used to pump a Tm-doped fiber laser, with the desired 1950 nm output (Fig. 1a, top). Here, we propose a new, highly attractive pumping scheme: The Ho:fiber is directly in-band pumped ($^5I_7$) by a 1950 nm semiconductor laser diode, removing the Tm:fiber, and the losses and instabilities associated with it, from the pumping scheme[2] (Fig.1a, bottom). This simplification potentially offers a more reliable, compact, and lightweight alternative to those previously described. Indeed, there may be certain technological applications where a lower power output and efficiency is tolerated in light of the practical advantages in the field.

Several existing designs of near 2-µm laser diodes based on InP and GaSb substrates have been reported, although not designed for the specific Ho-fiber pumping application[3-6]. Existing high-performance commercial laser designs are modelled so that their strained quantum-well (QW) width and alloy compositions are modified to provide 1950 nm peak emission. Typically, these are InGaAs QWs with InP substrates, and InGaSb QWs with GaSb substrates. An example of this for a GaSb-based laser[4] is shown in Fig. 1b. Our modelling indicates that the GaSb-substrate technologies possess superior laser performance at this wavelength, with more than double the internal efficiency (70%) and slope efficiency (0.64 W/A), as well as lower threshold currents than InP-based counterparts. This result is mostly due to suppressed Auger recombination in antimonide-alloys due to their large spin-orbit splitting, which is observed directly in the calculations (Fig. 1c). GaSb is identified as the preferred substrate choice for this application, although further optimization including doping, waveguide design to accommodate the large GaSb beam divergence, and the GaSb's low thermal conductivity are important to realize high-power laser diodes for Ho:fiber pumping applications. Possible solutions to these issues will be discussed.

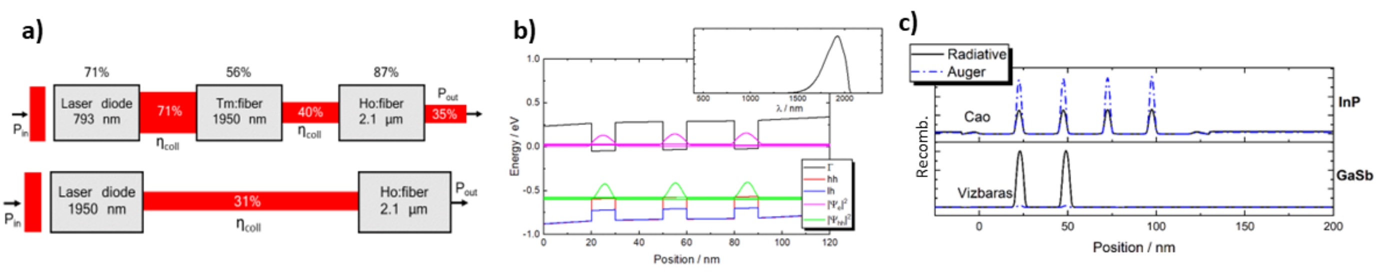

Fig. 1 a) Ho pumping schemes. Top: typical laser diode to Tm:fiber scheme Bottom: proposed direct diode scheme. b) Quantum well levels for 1950 nm emmission – inset is calculated spontaneous emmission from the quantum well. c) Radiative and Auger recomination rates in InP laser[5] (top) and GaSb laser[3] (bottom).

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References:**1)** Simakov, N., Hemming, A., Haub, J.G., & Carter, A. (2014). 2014 *The European Conference on Optical Communication* (ECOC), 1-3. **2)** Zervas, Michalis N. *Fiber Lasers XV: Tech. and Systems.* 10512. SPIE, 2018. **3)** Vizbaras, Augustinas, et al. *Quantum Sensing and Nano. Devices* XI. 8993. SPIE, 2014. **4)** Kelemen, M. T., *et al. IEEE photonics technology letters* 18.4 (2006): 628-630. **5)** Cao, Yuan-Ying, et al. IEEE Photonics Technology Letters 26.6 (2014): 571-574.**6)** Zhu, Si, et al. Opt. exp. 26.11 (2018): 14514-14523.