Abstract:

Rapid advancements in optics and laser technology have spurred significant interest in chip-scale integrated nanophotonic devices for realizing high-density photonic integrated circuits (PICs). These circuits integrates both active and passive elements on a single substrate. While compact passive waveguide structures form the backbone of PICs, the integration of active devices such as lasers and amplifiers are essential for realizing a fully functional all-optical system. Waveguide-based designs offer precise control over light propagation, enable tailored emission properties and enhanced beam quality.

This research primarily focuses on the development of on-chip rare-earth-doped waveguide lasers and amplifiers for integrated photonic applications, spanning from optical communication to matrix-based computing. Continuous-wave (CW) lasing was achieved in an ion-exchanged Yb-doped glass waveguide, demonstrating a record-low quantum defect of 0.66%. Additionally, pulsed laser operation was realized using a monolayer graphene saturable absorber, producing a pulse train with a 1 MHz repetition rate and a pulse width of 700 ns. On-chip optical pulse amplification in CMOS compatible $Er:Ta_2O_5$ waveguides were investigated. Amplification of both continuous wave (CW) and pulsed signals was achieved, with an integrated gain reaching up to 2.1 dB/cm. A comparative analysis with a commercial erbium-doped fiber amplifier (EDFA) revealed that the $Er:Ta_2O_5$ chip delivers signal amplification without introducing distortion. Additionally, the chip was tested for real-time optical communication, successfully transmitting data streams using both baseband and radio-over-fiber (RoF) schemes. To enhance the net optical gain of the $Er:Ta_2O_5$ chip, we investigated the impact of distributed pumping in extended $Er:Ta_2O_5$ spiral waveguides, which were carefully optimized to minimize bend losses. This approach led to gain improvements of 3.5 dB and 2.55 dB in co- and counter-propagating amplifier configurations, respectively. Furthermore, to harness the full potential of the $Er:Ta_2O_5$ material platform, we developed a selectively erbium-doped Ta_2O_5 photonic matrix processor employing wavelength division multiplexing based matrix-vector multiplication (WDM-MVM) for optical computation. The proposed architecture offers a compact, low-loss, and fully integrated solution for on-chip optical power generation, modulation, and information processing.