Graduate Research Projects; Photonics

Projects for Engineering Science, Electrical and Computer Engineering, Physics

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Noise Immune LiDAR with single photon sensitivity.

The precision of optical sensing and metrology is fundamentally dictated by the source and measurement of light. One important example is LiDAR, in which probe light is transmitted and received to determine the presence or absence of a reflective target. Recently, it has been shown that by measuring non-classical properties of quantum states of light, the effect of noise in the LiDAR detection channel can be reduced below the limit that is allowed by classical physics. However, the quantum light sources of such protocols are inherently limited to the single photon power level and cannot benefit practical far reaching LiDAR applications.

In this work, we proposed a classical LiDAR design[1] that is inspired by quantum LiDAR: while keeping the essential noise resilience advantage, it is equipped with high power classical source to effectively extend the target detection range. Its principle is based on coherent measurement of classical time-frequency correlation generated in the difference frequency generation (DFG) process. We experimentally demonstrated that the effect of indistinguishable noise light can be rejected by over 100dB using a sum frequency generation (SFG) receiver, and the system is still sensitive in single photon signal. A ranging experiment is also performed showing 0.1mm resolution for a 4m away target and velocity measurement capability.

The next step of this project is to devise a practical long range scanning LiDAR system with ultra-high resolution and noise resilience. Also, we are interested in adopting the LiDAR receiver principle in quantum information applications such as quantum frequency conversion.

Figure 1: Illustration of DFG process (left) and SFG process (right).

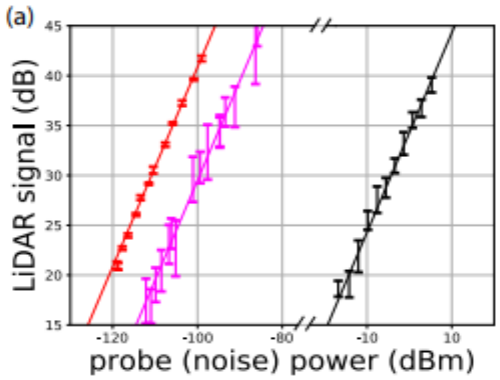


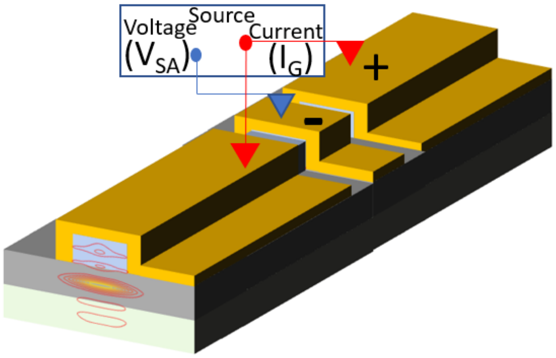
Figure 2: Over 100dB in band noise rejection. Black: noise power, Red: mirror target signal power, violet: Diffusive target signal power

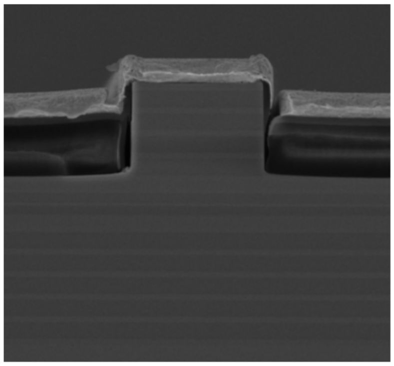
[1]Liu, Han, et al. "Compact All-Fiber Quantum-Inspired LiDAR with> 100dB Noise Rejection and Single Photon Sensitivity." *arXiv preprint arXiv:2308.00195* (2023)

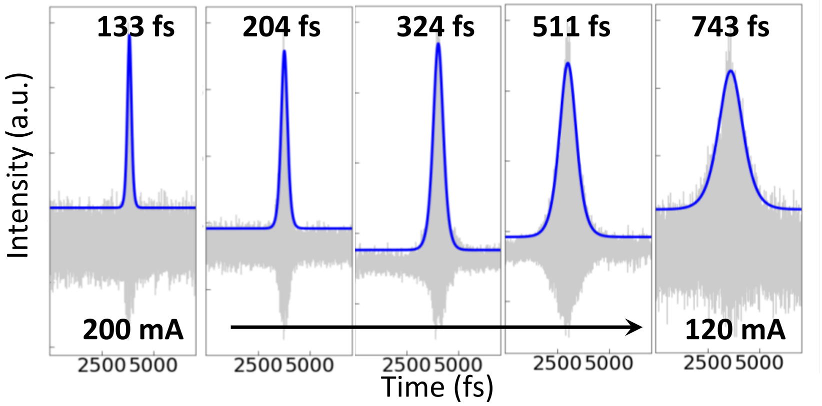
Ultrashort pulses in Bragg waveguide laser diodes

Monolithic semiconductor mode-locked lasers (MLLs) have emerged as pivotal tools, showcasing effective strategies for generating ultra-short pulses within an integrated platform. The incorporation of a saturable absorber (SA) into the laser architecture enables the realization of passive mode-locking (PML), a technique that facilitates the generation of pulses within a compact cavity with a high repetition rate. However, when operating within the wavelength range of 700-850 nm, MLLs encounter a critical challenge: the acquisition of an adequate gain bandwidth to support broadband mode-locking operation. Consequently, devices in this range often face limitations either in terms of lower average power output or pulse widths that exceed 1 picosecond. Notably, no existing reports explore the integration of quantum dots (QD) – which possess a substantially broader gain spectrum – for the development of mode-locked lasers emitting within the 700-850 nm range [6].

While higher peak powers and shorter pulse widths have been realized at wavelengths around 1.3 µm and 1.5 µm by harnessing QDs and quantum dashes in tapered waveguide configurations, achieving such performance benchmarks remains an outstanding challenge within the 700-850 nm range. This is due to a historical focus on bulk and quantum well MLLs, which have undergone extensive scrutiny over the past decades. Nonetheless, the attainment of subpicosecond pulse widths at high repetition rates within this wavelength range has remained elusive.







In this context, our breakthrough achievement gains heightened significance. By leveraging a unique Bragg waveguide laser structure, we have successfully bridged the gap between the longstanding limitations of MLLs operating in the 700-850 nm range and the pursuit of ultra-short pulses. The demonstration of a pulse width as short as 133 femtoseconds through a colliding pulse mode-locking configuration showcases our ability to overcome historical challenges and opens new landscapes for ultrafast photonics.

Candidates with doctoral degrees in physics, applied physics, electrical engineering or any related discipline will be considered. The post encompasses a strong experimental component, but some analytical skills will be required.

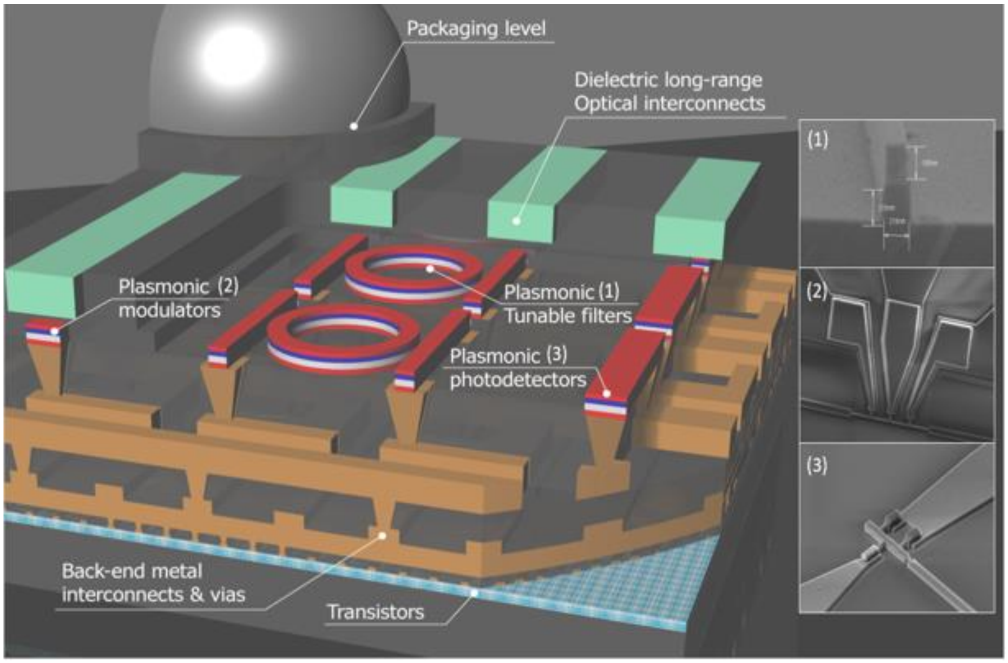
1. West, B. R., & Helmy, A. S. (2006). Dispersion tailoring of the quarter-wave Bragg reflection waveguide. Optics Express, 14(9), 4073-4086.
2. Iu, M. L., Zareian, N., Kang, D., Chen, E., Charles, P., Janjua, B., ... & Helmy, A. S. (2020). Electrically pumped efficient broadband CW frequency conversion in diode lasers using bulk χ2. APL Photonics, 5(1).
3. Janjua, B., Iu, M. L., Yan, Z., Charles, P., Chen, E., & Helmy, A. S. (2020). Passively mode-locked Bragg lasers with 64 GHz sub-300 fs pulses at 785 nm. IEEE Photonics Technology Letters, 32(18), 1135-1138.
4. Janjua, B., Iu, M. L., Leger, Z., Yan, Z., & Helmy, A. S. (2022). Colliding-Pulse Mode-Locking Produce 130 fs Pulses, Enabling Record X 2 Frequency Conversion. IEEE Photonics Technology Letters, 35(2), 105-108.
5. Janjua, B., Stirling, T., Iu, M. L., Yan, Z., & Helmy, A. S. (2023). High Peak Power Ultrashort Pulsed Passively Q-switched Mode-Locked Bragg Laser Diode. IEEE Photonics Technology Letters.

Nanophotonic interconnect using Plasmonics

The scalability of artificial intelligence, machine learning, and high-performance computing systems are increasingly limited by the performance of the electrical copper pins and wires that interconnect the various parts of the systems together. One potential solution is to switch to “photonic” interconnection, using photons instead of electrons for high-speed data transmission and communication. However, the physical footprints of photonic devices are typical orders of magnitude larger compared to nanoscale transistors. The scale-mismatch prevents efficient integration of photonics and electronics and in turn creates challenges such as low device integration density, thermal instability, and costly modifications to the standard CMOS manufacturing.

Plasmonics is a subset of photonics that introduces metal layers into photonic components and utilizes the interaction and energy exchange between photons and metal electrons to squeeze optical signals into device volumes that are comparable to electronics. Building on 10 years of research, our group has been developing plasmonic-based interconnect technology that can break the barriers of existing photonic solutions, with 10,000x higher bandwidth density compared to electrical counterparts while requiring one 10th of the power and latency.

Students involved in this research project will work within a multidisciplinary team to learn and contribute to the plasmonic technology. Students will be involved in (1) photonic device design using industrial-standard photonic/electronic software and (2) hands-on device characterization in photonic labs. Students with engineering science, ECE or physics backgrounds will be particularly suited for the project.



Helmy Group’s Plasmonic Interconnect Platform (C. Lin et al, Nano Lett. 20, 2950 (2020))