Exploring the hyperchaos of mid-infrared lasers

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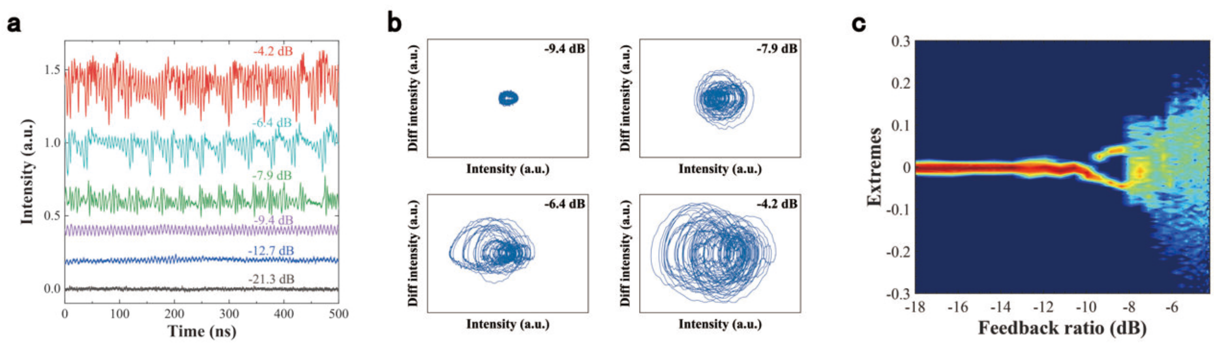

a, Time series of the laser for various feedback ratios. b, Phase portraits analysis. c, Bifurcation diagram shows the route to chaos via periodic oscillations. Credit: Yu Deng, Zhuo-Fei Fan, Bin-Bin Zhao, Xing-Guang Wang, Shiyuan Zhao, Jiagui Wu, Frédéric Grillot, and Cheng Wang

Chaos, often popularized as the 'butterfly effect', describes the irregular phenomenon of deterministic systems. Based on the unique features of sensitivity to initial conditions and unpredictability of future evolutions, chaos from laser diodes has found applications in private optical communication links, high-rate random number generations, Lidar systems, and optical computing networks. However, most chaotic light sources are operated in the near-infrared range, and hence the applications are limited to this spectral range as well.

A Chinese team of scientists, led by Professor Cheng Wang from

ShanghaiTech University, China recently reported a mid-infrared hyperchaos source in *Light: Science & Applications*. The chaos generation relies on interband cascade lasers, one major type of laser source in the mid-infrared regime. The lasers without any external perturbation usually produce continuous-wave output. In order to trigger the chaos production, the team applied an external perturbation known as 'optical feedback' to the lasers. Optical feedback is a technique where the laser output is reflected back to the laser cavity through a reflection mirror. The delayed light interacts nonlinearly with the laser device and generates chaos under certain operation conditions.

In the 1980s, mid-infrared chaos was produced from gas lasers including CO_2 lasers and He-Xe lasers. However, the gas lasers are rather bulky and the chaos bandwidth is limited to the megahertz range. In contrast, the chaos in interband cascade lasers, explored by the Chinese team, reaches the frequency coverage of gigahertz range. This broadband chaos is desirable for high-speed information processing and transmission. In particular, their analysis proved that the chaos produced several positive Lyapunov exponents rather than just one.

This suggests the chaos produced is, in fact, 'hyperchaos' of high-dimensional complexity. This high-order complexity is an essential requirement to implement secure communications in practice. In addition, the team pointed out that interband cascade lasers with optical feedback could produce hyperchaos within wide controlling parameter spaces, including bias current condition, feedback condition, and single or multimode lasing condition. "The broadband mid-infrared hyperchaos may enable applications in secure free-space communication links and remote chaotic Lidar systems," the scientists anticipate, "this is because the atmosphere has low-loss transmission windows (3 to 5 μm and 8 to 12 μm) in the mid-infrared regime."

More information: Yu Deng et al, Mid-infrared hyperchaos of interband cascade lasers, *Light: Science & Applications* (2022). DOI: 10.1038/s41377-021-00697-1

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