Optical and electrical bistability study sheds light on next-gen high speed data transfer

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Today, electrical bistable devices are the foundation of digital electronics, serving as building blocks of switches, logic gates and memories in computer systems. However, the bandwidth of these electronic computers is limited by the signal delay of time constants important to electronic logic operations. In an attempt to mitigate these problems, scientists have considered the development of an optical digital computer, and one team has gone so far as to demonstrate the optical and electrical bistability for switching in a single transistor.

This week, in the *Journal of Applied Physics*, a research team from the University of Illinois at Urbana-Champaign present their findings regarding the optical and electrical bistability of a single transistor operated at room temperature.

Prior to this work, quantum-wells were incorporated near the collector in the base of a III-V heterojunction bipolar transistor, resulting in a heavily reduced radiative spontaneous recombination lifetime of the device. The laser current modulation bandwidth is related to the electron-hole radiation recombination lifetimes, photon lifetimes and cavity photon density.

In a method patented by two of the article's authors, often referred to as Feng and Holonyak's idea, the optical absorption can be further enhanced by the cavity coherent photon intensity of the transistor laser. Using the unique property of intra-cavity photon-assisted tunneling modulation, the researchers were able to establish a basis of direct laser voltage modulation and switching at high gigahertz speeds.

The researchers found the transistor laser electrical and optical bistabilities to be controllable by base current and collector voltage. The current switching was found to be due to the transistor base operation shift between stimulated and spontaneous electron-hole recombination process at the base-quantum-well.

According to Milton Feng, of the research group, this was the first time this has been done.

"We put a transistor inside of an optical cavity, and the optical cavity controls the photon density in the system. So, if I use tunneling to absorb the photon, and then the quantum-well to generate the photon, then I basically can voltage-tune and current-control the electrical and optical switching between coherent and incoherent state for the light, and between stimulated and spontaneous recombination for the current," Feng said.

Compared to prior investigations, which contained optical hysteresis in cavities containing nonlinear absorptive and dispersive gain media, the operation principles as physical processes and operating mechanisms in transistor laser electro-optical bistabilities are considerably different. In this case, different switching paths between optical and electrical energy states results in different thresholds of input collector voltage, resulting in this considerable difference in method and results.

"Because of the switching path differences between coherent and incoherent cavity photon densities reacting with collector voltage modulation via Feng-Holonyak intra-cavity photon-assisted tunneling resulting in the collector voltage difference in switch-UP and switch-DOWN operations, the transistor laser bistability is realizable, controllable and usable," Feng said.

It is the researchers' belief the operations of the electro-optical hysteresis and bistability in the compact form of the transistor laser can be utilized for high speed optical logic gate and flip-flop applications.

"I hope the new domain for research will be extended from electronics—from bodies in electronics which transport in solid-state—into electronic-optical domain into an integrated circuit, which is going to be the big breakthrough for the future generation of high-speed data transfer," Feng said.

More information: M. Feng et al, Room temperature operation of electro-optical bistability in the edge-emitting tunneling-collector transistor laser, *Journal of Applied Physics* (2017). DOI: 10.1063/1.4989521

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