Small photonic-crystal lasers have offered one promising method for generating single photon sources, but research has only demonstrated devices that are optically pumped. A research team at the Korea Advanced Institute of Science and Technology (KAIST; Taejon, Korea) recently demonstrated an electrically driven, single-mode, low-threshold current (~260 µA), photonic bandgap laser that operates at room temperature.

Research team leader Yong Lee says the team’s small step toward creating a single-photon source may be of special interest to researchers working with photonic crystals, cavity quantum electrodynamics, and quantum information.

"One of the biggest problems we faced in trying to create a single-cell free-standing photonic-crystal laser was how to make electrical contact with the tiny sub-micron-sized photonic-crystal resonator structure," Lee says. "In the end, we sat the resonator on a sub-micron post that was large enough for good electrical activity and small enough not to disrupt resonator performance."

The group used an inverted heterojunction (n-i-p instead of p-i-n) structure that limits bimolecular recombination to the area around the sub-micron central post. This, in turn, utilizes the low mobility of the hole to generate photons. The team placed an indium phosphorous semiconductor post at the center of a single-cell photonic-crystal resonator. The post was 1.0 µm high and 0.64 a by 0.51 a, where a is the lattice constant of the photonic crystal.

"The post connected to a 50-µm diameter mesa, which consisted of a modified single-cell photonic-crystal cavity surrounded by five heterogeneous photonic-crystal sections with the same lattice constant but different sizes of air holes," Lee says. "This heterogeneous surrounding improved [our ability to] position and size the central post."

The team found that the size of the air holes affected the speed of the post-etching process. By modifying the air-hole size, they could improve the position and size of the post. In addition, the chirped resonator structure improved the Q factor slightly without changing either resonant frequency or modal volume of relevant modes. "We confirmed that with 3-D finite-difference time-domain calculations," Lee says.

The team electrically pumped the single-cell photonic-crystal cavities at room temperature, using ~6-ns pulses for a period of 2.5 µs. Emitted photons were collected by a 50X microscope and fed to a spectrometer. "With this process," Lee says, "we observed single-mode lasing action at 1519.9 nm. Still, several issues remain to be addressed before this electrically driven, ultra-small cavity can become a practical on-demand single-photon source," Lee says. Issues to be solved include how to place well-defined quantum dots or impurity atoms at the antinode of the cavity and how to inject single electron-hole pairs efficiently. Lee estimates it will be several years before a realistic single-photon gun is achieved. "Nevertheless," Lee says, "we believe the demonstration of an electrically driven single-cell photonic-crystal laser represents a small but meaningful step toward the ultimate photon source."

Toshihiko Baba of Yokohama National University (Yokohama, Japan) said that Lee’s electrically pumped photonic-crystal laser was an important step after researchers at the California Institute of Technology (Pasadena, CA) first demonstrated an optically pumped single-cell crystal laser. It is a very promising step toward creating a functional photonic chip, practical single-photon emitter, or sensing photon source, he adds.

— Charles Whipple