No liquid helium, but still extremely cool

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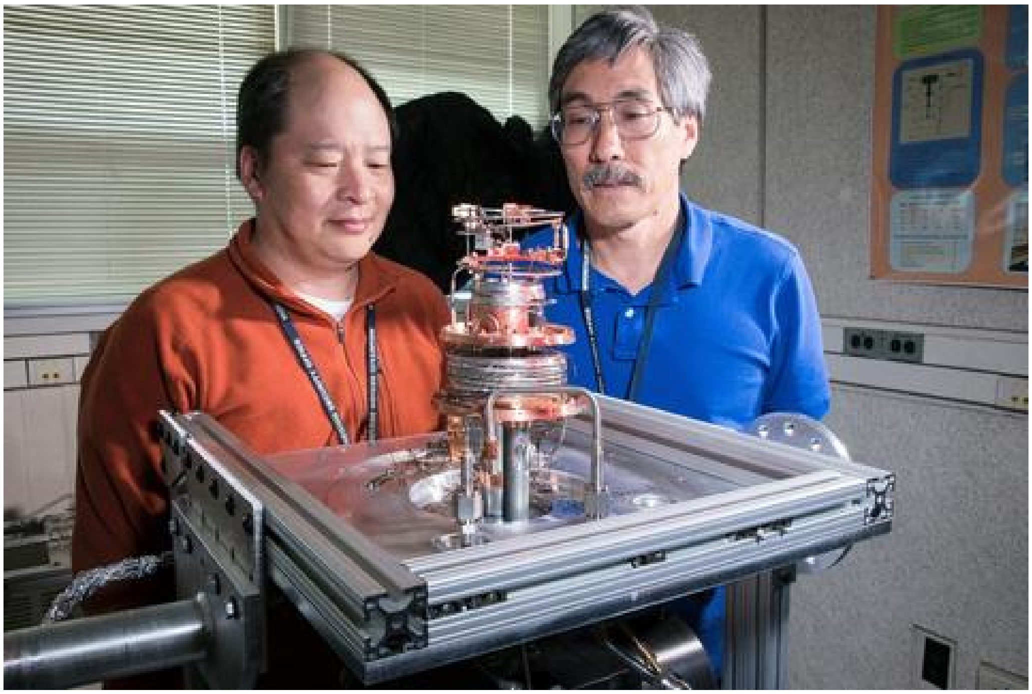

Sae Woo Nam (left) and Vincent Kotsubo examine the prototype for their new cryocooler. Credit: National Institute of Standards and Technology

NIST scientists have devised a novel hybrid system for cooling superconducting nanowire single-photon detectors (SNSPD) – essential tools for many kinds of cutting-edge research – that is far smaller than those previously demonstrated and that eliminates the need for conventional cryogens- such as liquid helium.

SNSPDs are utilized in ultra-secure quantum communications, defect analysis of small-scale integrated circuits, laser-based light detection and ranging (LIDAR), and biological research, among many other applications. Dimensions of an individual detector are not much larger than the width of a human hair. Because they are based on superconducting materials, they operate at extremely low temperatures only a few kelvins above absolute zero.

Historically, that level of cooling has typically been achieved with liquid-helium systems that are costly, complicated, large, and demand considerable expertise to operate and maintain safely. In recent years, there has been growing worldwide interest in finding alternatives. The NIST work is a milestone in that effort.

"SNSPDs could be deployed much more widely if a compact, low-power cooling system was available," says NIST physicist Sae Woo Nam, who developed the new method with NIST colleagues Vincent Kotsubo, Joel Ullom, and others.

"When we began our work, no such system existed," Nam says. "The closest thing to it was a device about the size of a water heater that draws 1.5 kilowatts of power. That's unnecessarily high. Although we need to cool the SNSPDs to very low temperatures, the size and nature of the devices are such that the amount of heat to be removed is quite small – in the neighborhood of a few hundred microwatts."

The team's prototype cooler, drive, control electronics and instrumentation is 0.31m high and 0.61 m long. When all the engineering work is completed, the scientists believe that it will easily fit in a standard electronics rack. Its power demand is about 250 watts.

"This work is also in line with one of NIST's goals—the development of 'invisible' cryogenic systems," says Kotsubo, the lead designer of the system. "That is, they are not only physically small and require low power, but they are practically 'black box' devices – users just have to turn it on and it works. That will help overcome a common psychological barrier that cryogenics is technically hard and dangerous."

The NIST team's current prototype device, described in *IEEE Transactions on Applied Superconductivity*, goes a long way toward that objective. It relies on a hybrid cooling system comprising a Joule-Thomson cryocooler (JT) and a pulse-tube refrigerator (PTR). Both share some common elements with the cooling system in a home refrigerator: A gas is alternately compressed and then allowed to expand, shedding thermal energy to an exchanger that removes heat from the system. The system is completely closed. "We recirculate the gas continuously, compressing it and recompressing it," Kotsubo says.

The PTR can reach temperatures as low as 10 K. It is used to precool the JT, which can reach below 2 K. SNSPDs have required operating temperatures in the 1 K – 2 K range.

"We're shrinking things down to a scale where there aren't any engineering rules of thumb to help guide you in the design, or decide what materials to use," Nam says. "Only a handful of people have done any work in this area. Everything is custom-made except the compressors. We're trying to come up with a design that can actually be manufactured."

The initial planning was supported by the National Security Agency, which has an ongoing interest in small-scale, portable telecommunications apparatus. "They wanted a paper study," Nam says, "and Vince did it. It looked like we could actually build something, so NSA funded the beginning part of building the prototype."

The project – which is still in the early stages—now receives funding under a cooperative research and development agreement (CRADA) with a Michigan company called Quantum Opus, which expects eventually to commercialize the technology. The firm is supported by a Small Business Innovation Research grant from the Defense Advanced Research Projects Agency (DARPA).

The founder of Quantum Opus, physicist Aaron Miller, believes that "this will be the smallest, lowest-power continuously-operating cryogenic system capable of reaching less than 2 kelvins. Ideally it could move experiments that usually would be tied to a high-voltage wall plug and water cooling system into more mobile environments such as aircraft and telecommunication data closets. As with many DARPA projects, the applications are not fully known yet. But hopefully the existence of this system will get people interested in new applications previously thought impossible."

"I'm excited about the long-term goal of making cryogenics invisible to the end user," Nam says. "That way people can focus on the problems they're trying to solve instead of spending great deal of time on complicated cooling systems.

"This is part of a larger effort in which organizations could save millions of dollars by going cryogen-free. With the right investment in strategic areas like this, simplifying the measurement infrastructure can have a huge impact."

More information: Vincent Kotsubo et al. Compact 2.2 K Cooling System for Superconducting Nanowire Single Photon Detectors, *IEEE Transactions on Applied Superconductivity* (2017). [DOI: 10.1109/TASC.2017.2657682]

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