New varactor enhances quantum dot device measurements at millikelvin temperatures

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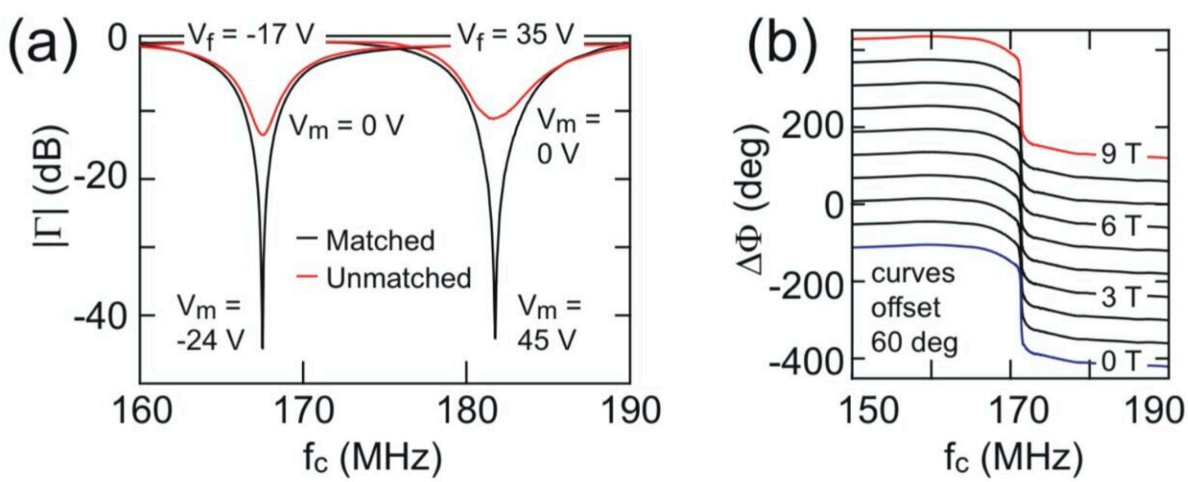

a, The resonance frequency and impedance matching can be independently tuned using appropriate combinations of V_f and V_m as indicated. b, Phase response as a function of magnetic field with the varactors tuned to impedance matching. No change is observed in the resonance frequency or matching over a range of 9 T. Credit: *Nature Electronics* (2024). DOI: 10.1038/s41928-024-01214-z

The development of quantum computing systems relies on the ability to rapidly and precisely measure these systems' electrical properties, such as their underlying charge and spin states. These measurements are typically collected using radio-frequency resonators, which are tuned using voltage-controlled capacitors known as varactors.

Researchers at University College London (UCL) recently developed a new varactor based on materials that exhibit quantum paraelectric behavior. Their proposed device, introduced in a paper published in *Nature Electronics*, can optimize the radiofrequency read-outs of quantum dot devices at low temperatures down to a few millikelvin (mK).

"To conduct our research on quantum devices, we use radio-frequency resonators for readout," Mark Buitelaar, co-author of the paper, told Phys.org. "To optimize this readout—such as tuning the resonator frequencies or their coupling to transmission lines—we needed tunable capacitors—also known as varactors—that are robust, insensitive to magnetic fields and, most importantly, work at temperatures only a few mK above absolute zero."

Varactors are widely used within the semiconductor industry, yet so far they have not been applied to quantum technologies. This is because they operate poorly or do not work at all at the very low temperatures at which quantum technologies operate.

As part of their recent study, Buitelaar and his colleagues set out to develop a new varactor that would operate well at these low temperatures. The device they created is based on strontium titanate and potassium tantalate, two materials that display quantum paraelectric properties and a large field-tunable permittivity at low temperatures.

"Any paraelectric material can be used as the basic component of a varactor, as their permittivity is tunable using electric fields—that is, by simply applying a voltage," Buitelaar explained. "What makes quantum paraelectric materials such as strontium titanate special is that these paraelectric properties are preserved down to absolute zero."

Buitelaar and his colleagues assessed the performance of their varactors in a series of tests and found that they work extremely well at low temperatures down to 6 mK. These are the temperatures at which they operate their quantum dot devices.

"The varactors enabled us to significantly increase our signal-to-noise rations and therefore the precision and speed of our measurements," said Buitelaar. "We expect our varactors to be of interest to many other researchers that use devices that only operate at extremely low temperatures, such as qubits in semiconductors or superconducting materials."

As part of their recent study, the researchers used their varactor to optimize the radiofrequency read-out of carbon nanotube-based quantum dot devices they developed. When applied to these devices, the varactor attained a charge sensitivity of 4.8 μe $Hz^{-1/2}$ and a remarkable capacitance sensitivity of 0.04 aF $Hz^{-1/2}$.

"Together with colleagues from the London Center for Nanotechnology at UCL, we are currently working on dopants in silicon as the building blocks of a quantum processor," added Buitelaar. "The quantum paraelectric varactors certainly help optimize the measurement precision and speed of our quantum state readout, which will be quite important as the quantum circuits are scaled up to larger systems."

More information: P. Apostolidis et al, Quantum paraelectric varactors for radiofrequency measurements at millikelvin temperatures, *Nature Electronics* (2024). DOI: 10.1038/s41928-024-01214-z

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