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# Study shows the non-exponential decay of a giant artificial atom

August 29 2019, by Ingrid Fadelli

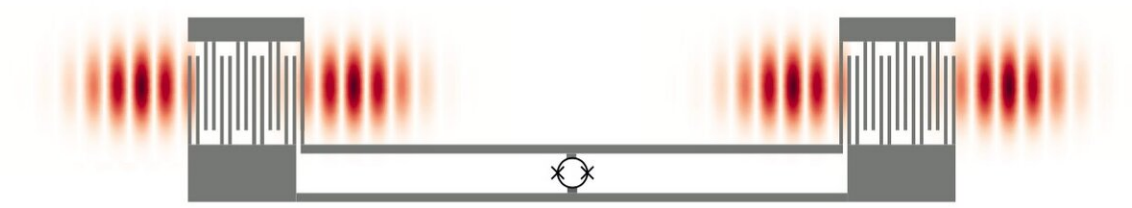

Figure representing the researchers' experimental setup. Credit: Andersson et al.

To date, research in quantum optics has primarily investigated the relation between light and matter using small atoms interacting with electromagnetic fields that have substantially larger wavelengths. In an unconventional new study, a team at Chalmers University of Technology in Sweden and the Max Planck Institute for the Science of Light set out to explore the interaction between a large atom and acoustic fields with wavelengths several orders of magnitude below the atomic dimensions.

In a previous study, some of the researchers from the same group showed that artificial atoms based on superconducting qubits can be coupled piezoelectrically to surface acoustic waves. When comparing the sound-matter interaction they observed with the more conventional light-matter interaction, they found that the two are actually very similar.

Inspired by these observations, they set out to probe the physics of the light-matter interaction in acoustic systems. However, they found that this could only be done within parameter regimes that are challenging, if not impossible, to achieve without using sound.

"We realized that the slow propagation speed of sound would let us engineer artificial atoms with internal time delays, or 'giant' atoms as we like to call them," Gustav Andersson, one of the researchers who carried out the study, told Phys.org. "Our goal was to find out how this regime was different from the more standard case of small atoms, what the absorption and emission of phonons from a giant atom would look like."

To reach the 'giant atom regime' they wanted to investigate, the researchers took advantage of a key feature of sound waves—specifically, their slow propagation rate. In fact, the propagation rate of sound waves is around 3000 m/s, which is five orders of magnitude slower than light.

Andersson and his colleagues made the artificial atom interact with sound at two separate points. For their experiment to work, however, the distance between these two points had to be large enough to ensure that the time in which the waves propagated across them was longer than the timescale of photon absorption and emission.

The approach adopted by the researchers could be compared to controlling an atom's radiation by attaching it to an antenna. As the velocity of the sound waves is low, it takes longer for their field to propagate across the giant atom, giving rise to what is known as non-Markovian dynamics.

"We made the artificial atom interact with sound through interdigital transducers (IDTs), a periodic finger structure whose period matches the wavelength of the surface acoustic waves," Andersson explained. "We created this separation by effectively using two IDTs that are electrically connected. We then used microwave measurements at low temperature, standard techniques for superconducting circuits, to study the properties of the giant atom."

The experiment carried out by Andersson and his colleagues yielded several interesting observations related to the interaction between sound and matter. For instance, the researchers were able to demonstrate the non-exponential decay and the novel scattering properties of giant atoms. These newly discovered features are caused by the time-delay effect (i.e. non-Markovian process) at the single-atom level.

"The traditional framework of quantum optics is based on point-like atoms and neglects the time it takes for light to pass a single atom," Lingzhen Guo, another researcher involved in the study, told Phys.org. "In order to explain the observations gathered in our experiments, however, we have to consider both the size effect and the time delay of the atom. Therefore, the study of giant atoms represents a new paradigm in quantum optics."

The recent work of Andersson, Guo and the rest of their team demonstrates the non-Markovian nature of a giant atom in the frequency spectrum, while also unveiling its non-exponential decay over time. In the future, they would like to carry out additional studies that might increase the relevance of acoustic systems in quantum information processing by exploiting their advantages over purely electrical circuits.

"Due to the short wavelength of sound, surface acoustic wave resonators can be designed to support many more resonant modes than their electromagnetic counterparts," Andersson said. "By coupling these modes together with superconducting circuits, we hope to create complex quantum states in a hardware-minimal fashion. It would be exciting to see whether such systems could be used for simulating solid-state quantum systems or certain schemes to realize quantum computing."

**More information:** Gustav Andersson et al. Non-exponential decay of a giant artificial atom, *Nature Physics* (2019). DOI: 10.1038/s41567-019-0605-6

Citation: Study shows the non-exponential decay of a giant artificial atom (2019, August 29) retrieved 27 March 2023 from https://phys.org/news/2019-08-non-exponential-giant-artificial-atom.html