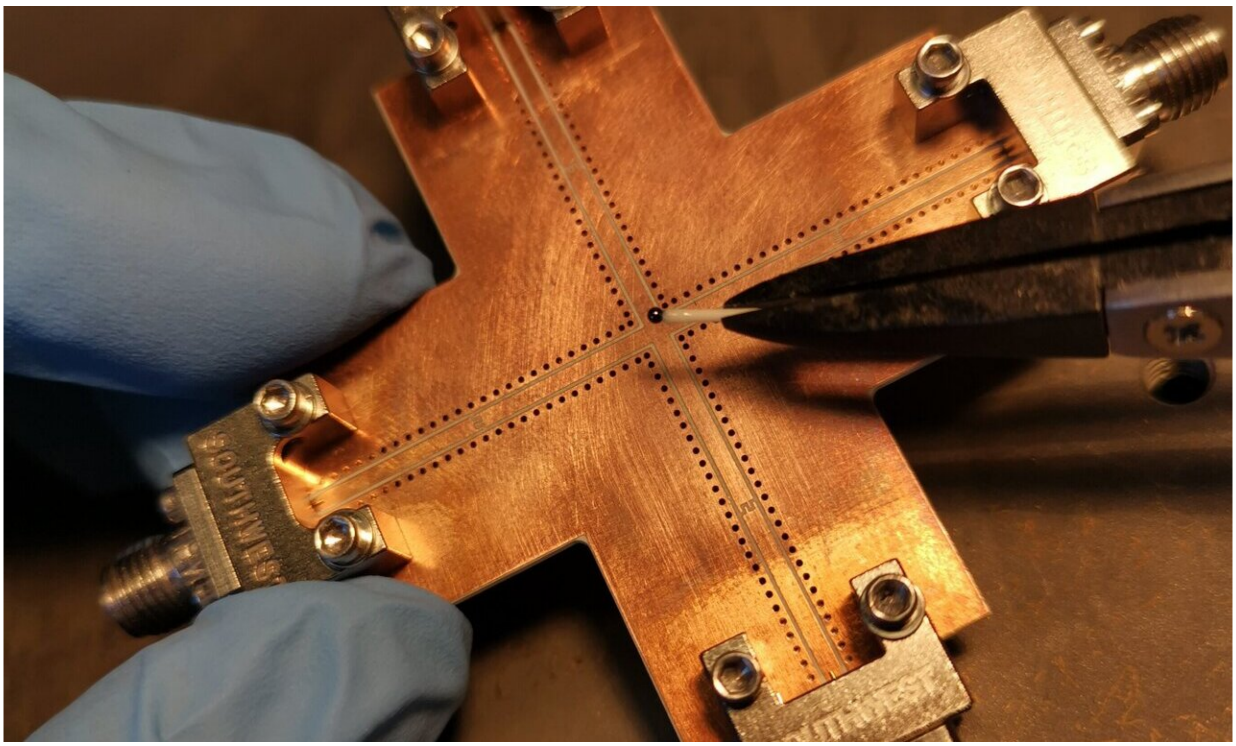
Producing dissipative coupling in hybrid quantum systems

October 3 2019, by Ingrid Fadelli



Credit: Dynamic spintronics group / University of Manitoba

As quantum objects are susceptible to their surrounding environment, quantum coherence and quantum states can easily be destroyed due to the impact of external signals, which can include thermal noise and backscattered signals in the measurement circuit. Researchers have thus been trying to develop techniques to enable nonreciprocal signal propagation, which could help to block the undesired effects of backward noise.

In a recent study, members of the dynamic spintronics group at the University of Manitoba in Canada have proposed a new method to produce dissipative coupling in hybrid quantum systems. Their technique, presented in a paper published in *Physical Review Letters*, enables nonreciprocal signal propagation with a substantial isolation ratio and flexible controllability.

"Our recent work on nonreciprocity in cavity magnonics is grounded in a research area combining cavity spintronics and hybrid quantum systems, which holds promise for constructing new quantum information processing platforms," Yi-Pu Wang, a postdoctoral researcher at the University of Manitoba who was involved in the study, told Phys.org.

Over the past few decades, studies in the field of quantum technology have mainly explored mechanisms of coherent coupling between subsystems, as dissipative coupling mechanisms had not yet been widely considered and utilized in hybrid quantum systems. Last year, however, the same team of researchers at the University of Manitoba unveiled an intriguing new type of dissipative magnon-photon coupling.

"This discovery immediately gave us a lot of inspiration, because dissipative coupling can be used to break time-inversion symmetry due to its inherent dissipative properties," Wang said. "This drove us to create systems that combine dissipative and coherent coupling effects to achieve nonreciprocal properties."

In their new study, Wang and his colleagues set out to develop a device with high isolation and low insertion losses in the linear regime, as these characteristics could aid the development of quantum information technologies. The device they created has two key components: a planar cross-shaped microwave circuit and a small yttrium iron garnet (YIG) sphere.

"Our device works equivalently to a microwave diode, which allows microwaves at certain designed working frequencies to propagate in only one direction," Jinwei Rao, a Ph.D. student at the University of Manitoba who was involved in the study, told Phys.org. "The planar cross circuit was specially designed to support the formation of standing waves and allow traveling waves to flow over it."

By placing the YIG sphere on top of the microwave circuit, the researchers were able to prompt cooperative interactions between the traveling waves, standing waves, and magnetic spins. These interactions allow both coherent and dissipative coupling effects to be sustained over time.

Wang, Rao and their colleagues observed that the relative phase between these coupling effects is dependent on the propagation direction of the input microwave signal. Remarkably, in the cavity magnonic system they developed, this microwave signal produces nonreciprocity and unidirectional invisibility.

The researchers also developed a simple model that outlines and captures the general physics behind the interference between coherent and dissipative coupling. They found that this model accurately described observations gathered over a broad range of parameters.

"Our model is described by a non-Hermitian Hamiltonian where the coupling strength between the photon and magnon excitations is a complex number," Wang explained. "The real part of this coupling strength represents the coherent coupling effects, and the imaginary part represents dissipative coupling effects."

The model proposed by the researchers suggests that coherent coupling is somewhat similar to the interaction between two mechanical pendulums connected by elastic springs. Dissipative coupling, on the other hand, resembles the interaction between two pendulums connected by a shock absorber, which introduces a friction that in turn leads to the dissipation of energy.

In the nonreciprocal device created by Wang, Rao and their colleagues the relative phase between the effects of coherent and dissipative coupling is described as a phase term. This phase term is closely related to the loading configuration of the input microwave signal.

"The interference effects always correspond to the role of cross terms," Wang said. "As a rule, the interference effect between A and B is reflected in the mathematical term of A multiplied by B, which can come from the square of (A±B). The cross term of the coherent and dissipative couplings originated from the square term of the complex coupling strength appears in the transmission coefficient."

The study is among the first to introduce a method to produce dissipative coupling in cavity magnonics systems. Using this new method, the researchers were able to achieve nonreciprocity in a coupled system, in a way that could also be extended to coupling in other physical systems or at different frequency ranges.

As the interplay between coherent and dissipative coupling is believed to be a fairly common phenomena in coupled systems, the approach introduced by the researchers could inspire further research in other areas of physics. Moreover, although the device they developed is quite simple, they found that it contained and demonstrated new and elegant physics effects.

"Prior to this, coherent coupling was a hot area of research, although dissipative coupling was also studied by some physicists in select fields," Wang said. "However, these forms of coupling were generally studied independently, as they were seen as controlling their own unique physical laws. We found that when these two forms of coupling are combined in the same system an unusual reaction takes place, with our experiment systematically demonstrating for the first time the peculiar physical phenomena that arises in the cavity magnonics system."

The recent work carried out by the dynamic spintronics team at the University of Manitoba opens up a new path for the development of quantum technology, by outlining the dynamics of dissipative photon-magnon coupling in hybrid quantum systems. The nonreciprocal physics dynamics outlined by their model could eventually inform the design of different functional microwave devices with many possible applications, including isolators, circulators, sensors and switchers.

"As a first step, our group is now focused on inventing a miniaturized portable microwave isolator that may surpass the technical performance of commercially available products," Dr. Can-Ming Hu, the head of the dynamic spintronics group at the University of Manitoba, told Phys.org. "Such a device is highly demanded by the international community developing quantum information technologies, on which the Canadian government, alongside the US, UK, Japan, and China, are investing heavily. The future is very bright for continuing research on this new path of Cavity Spintronics."

More information: Yi-Pu Wang et al. Nonreciprocity and Unidirectional Invisibility in Cavity Magnonics, *Physical Review Letters* (2019). DOI: 10.1103/PhysRevLett.123.127202

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