Robust Time Crystal in Semiconductor Electron-Nuclear Spin System

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Frank Wilczek introduced the concept of time crystals in 2012 for closed many-body systems in thermodynamic equilibrium. While it turned out to be prohibited in its original form, time-crystalline behavior demonstrating spontaneous breaking of the time translation symmetry was predicted to be feasible in non-equilibrium conditions and offer an attractive avenue for exploring non-equilibrium matter states.

This study demonstrates the realization of highly robust, non-decaying auto-oscillations under continuous excitation in a tailored semiconductor's electron-nuclear spin system. These oscillations form a continuous time crystal (CTC) state based on the dissipative many-body system. Our findings establish robust CTC dynamics (limit cycle), as seen in Fig. 1, over a wide range of control parameters, including laser power, temperature, and magnetic field. The coherence time of the periodic oscillations, indicative of the ideal ordering of “time atoms” within the CTC, is defined by the experimental measurement time and extends to several hours. Additionally, we observe the presence of chaotic oscillations, signaling the melting of the CTC. This research provides valuable insights into the dynamic regimes of CTC state [1].

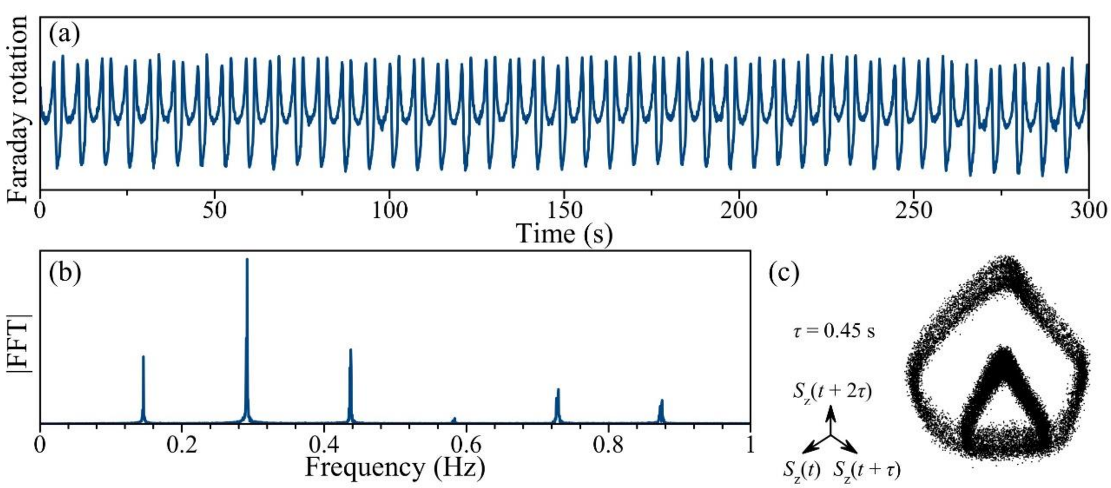

Fig. 1 (a) Periodic oscillations of the electron spin polarization - robust CTC state. (b) The fast Fourier transformed for the 40 minutes of the time spectrum from panel (a). (c) Phase portrait representing a limit cycle in time-delay coordinates with time delay $\tau = 0.45$ s. Each black point corresponds to the data point at a certain time.

Moreover, by harnessing the robust CTC platform, we've delved into the non-linear dynamics achieved by deviating from continuous driving through periodic modulation of the exciting laser polarization. This deviation leads to a wide array of phenomena, from synchronization to chaotic motion, that depend on the frequency and depth of the modulation. These effects demonstrate the transition from continuous to discrete time crystal and hold promising potential for practical applications.

References

[1] A. Greilich, N. E. Kopteva, A. N. Kamenskii, P. S. Sokolov, V. L. Korenev, and M. Bayer, Nature Physics **20**, 631 (2024).