Enhancing quantum memories by means of Light-Matter Interference (EEVI)

Improving existing quantum memory protocols by increasing storage and retrieval efficiencies without increasing control power or optical depth

Proposed Use

The technology described provides a novel approach to significantly improve many existing quantum memory protocols by increasing the storage and retrieval efficiencies without requiring additional control power or optical depth, while simultaneously retaining high optical bandwidth suitable for high-speed operation.

This novel method makes use of quantum interference between the signal light and stored material excitation to enhance memory storage and retrieval efficiency. An incoming signal is partially stored in the memory, leaving a portion transmitted through the memory. By looping the non-stored signal back into the memory, it interferes with the matter wave resulting from the previously stored signal component, enhancing the storage efficiency. Similarly, the method can enhance the retrieval efficiency by interfering the initially retrieved signal with the excitation remaining in the memory. Numerical simulations indicate that the storage and retrieval efficiency can be increased to >99% by temporal shaping of the control pulses that drive the memory, with lower demands on the control intensity and optical depth.

Problem Addressed

Photonics has proven to be a key platform for quantum computers, quantum sensors and quantum networks. Light enables interfacing quantum nodes over long distances, essential for secure communication, distributed quantum computing and for the development of a quantum internet. Quantum memories are a crucial component in these systems. A key challenge for quantum memories is to achieve the efficiencies needed to properly scale quantum networks in size and in distance for high bandwidth signals..

To achieve high efficiencies, quantum memories require strong light-matter coupling, which can be achieved through large optical depths and high control field intensities or by placing the storing medium inside an optical cavity. The principal approach of this invention is to improve memory efficiency for both resonant and off-resonant protocols, without the need for any of these parameters to be increased, and without the use of a cavity.

Benefits

- Enhances efficiency of quantum memories while requiring less optical depth and lower control field intensities than a conventional memory achieving the same efficiency.
  - Beneficial for scalability and reduced noise
  - Increases feasibility of platforms such as cold atoms or solid state devices
  - Compatible with a multitude of quantum memory protocols
- Storage and retrieval efficiency can be increased to >99%
- For applications requiring a highly single mode memory, this method allows retains the memory single-mode-ness even at high efficiencies

Edmond Yau

Commercialisation Executive – Faculty of Natural Sciences

h.yau@imperial.ac.uk

Technology reference: 11810

IMPERIAL
ENTERPRISE

Enhancing quantum memories by means of Light-Matter Interference (EEVI)

Problem addressed (continued)

The concept of this Efficiency Enhancement via light-matter Interference (EEVI) protocol is shown in Figure 1a, along with experimentally measured results in Figure 1b. Our numerical model fits the data well (solid lines in Figure 1b). Using the same numerical model with optimised control pulse shapes results in the improvement in total efficiency shown in Figures 1c and 1d. In Figure 1c, we limit the optical depth and compare a standard Raman memory with EEVI-Raman, highlighting how EEVI could be applied in cold atom systems or in micro-vapour cells. For Figure 1d, we instead show a warm atomic ensemble with high optical depth but limit the maximum Rabi frequency of the control field. **In all cases, EEVI enhances the total efficiency.**

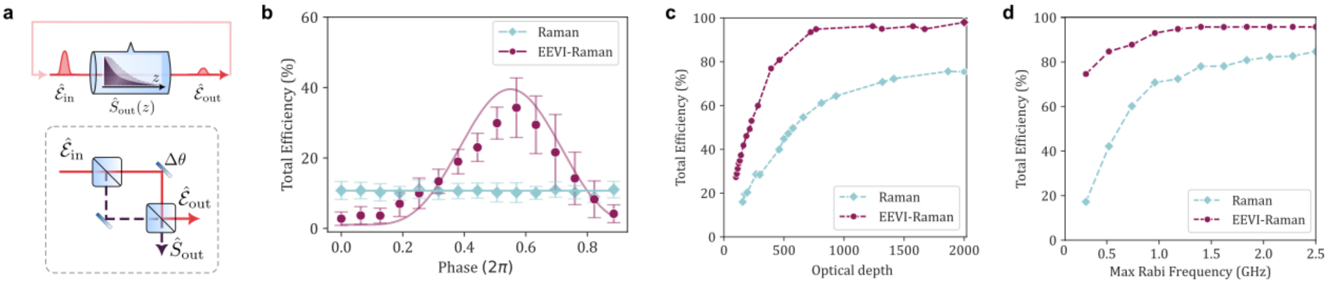

Figure 1. (a) Concept of the EEVI protocol. An input signal, E_{in}, is partially stored as an atomic excitation, S_{out}, in an interaction that is analogous to a light-matter beam splitter. The un-stored portion of the signal is then looped back into the memory for a second write process where interference occurs between the looped optical field and the stored atomic excitation, analogous to a Mach-Zehnder interferometer (b) Experimentally measured total efficiency as a function of relative phase between the two mapping procedures, for a standard Raman memory protocol (Raman) and the Raman memory protocol enhanced using the EEVI method (EEVI-Raman) The solid lines are the result of numerical modelling with experimentally measured parameters. (c) Results of numerical optimisation on the control laser pulses mediating the memory mapping procedure, as the optical depth is varied, for a standard Raman memory and EEVI-Raman. (d) Results of numerical optimisation when fixing the on-resonant optical depth to 2300 and limiting the peak Rabi frequency available for the control mapping field.