Slow light on a chip

By exploiting optical quantum interference in integrated atomic vapour cells, Holger Schmidt and co-workers have achieved the slowest on-chip light propagation speed reported to date.

What is your work about?

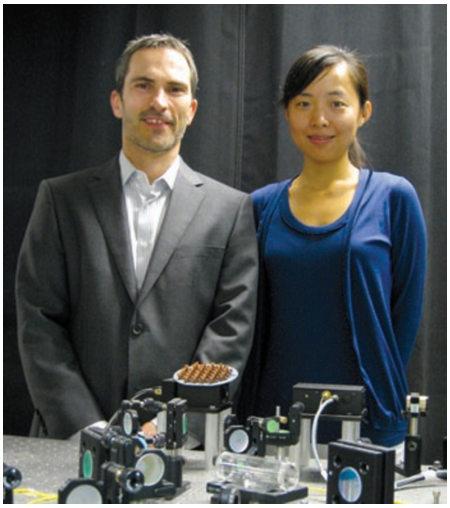
We have demonstrated slow light and electromagnetically induced transparency above room temperature in an atomic spectroscopy chip that is self-contained and compatible with other integrated photonic elements. Our work combines the strength of quantum interference in atomic vapours with the convenience of integrated optics. Our results show that atoms, chip-scale photonics and quantum interference effects are all compatible. The thought of confining atoms to waveguides is intriguing because it makes it possible to maintain very high optical intensities over extended distances with low-power light. This is especially important for studying nonlinear optical effects.

What has been previously achieved?

Optical quantum interference effects are known to create strong light–matter interactions that result in dramatic and often counterintuitive effects, such as rendering an opaque medium transparent, slowing down the velocity of a light pulse and lasing without population inversion. In the past, these effects were typically restricted to esoteric media (Bose–Einstein condensates, for example) or ultralow temperatures. Quantum-interference-based slow light was first investigated in the mid-1990s. We drew inspiration from the past demonstration of slowing light to 90 m s^{-1} in hot rubidium vapour and the development of miniature atomic vapour cells based on microelectromechanical systems. More recently, quantum interference was demonstrated in both molecules and atomic vapours within hollow-core photonic-crystal fibres. These hollow waveguides have dimensions similar to what we used, but such systems are currently not self-contained or integrated within a chip-scale platform.

Tell us about your results.

The low phase index of atomic vapour makes it challenging to guide light through microscale channels filled with such media. Together with colleagues John Hulbert, Evan Lunt, Katie Hurd and Aaron Hawkins at Brigham Young University, we used antiresonant reflecting optical waveguides, in which light is confined in low-index media by using one or more high-index cladding layers. This allows us to combine hollow-core waveguides with solid-core optical waveguides on a single chip to get light to the confined rubidium atoms. We have developed a method of attaching the atomic vapour reservoirs directly on top of the chip to create stand-alone vapour cells. To ensure sufficiently strong quantum interference, we coated the walls of the hollow cores with a monolayer of an organic material, which reduces the loss in electron coherence when the atoms collide with the walls. By doing so, we created a coin-sized photonic atomic spectroscopy platform in which alkali vapours are confined to microscale hollow waveguides. This technique can be used to create an optically dense vapour, which is essential for unambiguously observing strong quantum interference effects. Indeed, we were able to clearly observe both hallmarks of linear quantum interference: transparency and slow light. The reduction in pulse velocity by a factor of up to 1,200 — the largest achieved in any waveguide-based photonic structure — allowed us to spatially compress 6-m-long pulses to 5 mm within the chip.



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Holger Schmidt and Bin Wu with their experimental set-up and atomic spectroscopy chip.

How does your device work?

The effects we observed are based on electromagnetically induced transparency. If we apply two laser fields between two distinct ground states and a common upper state in a suitable system such as a rubidium atom, the electron wavefunction has a new eigenstate that is a phase-coherent superposition of the two lower levels. Electrons in this 'dark state' have no probability of transitioning to the upper level, and thus the medium becomes transparent at a frequency where a single beam would usually be resonantly absorbed. The duration for which this coherence can be preserved determines how perfect the transparency will be. This transparency is confined to a limited frequency range, and the resulting strong dispersion is responsible for slow light propagation. The absence of linear absorption allows us to tune laser fields directly to an atomic resonance, which strongly increases nonlinear interactions.

What are the potential applications?

Slow-light chips can be used for optical buffering and signals processing in communications systems, microwave photonics, phased-array beam shaping and so on. Other examples that take full advantage of the high waveguide-mode intensities at small input powers down to the few-photon level include all-optical switching, quantum non-demolition photon detection and the generation of entangled photon pairs for quantum communications, quantum cryptography and quantum lithography.

How can the technique be improved?

Chip durability and decoherence are two areas that can be further improved. The sealing methods can be refined to improve the long-term stability of the rubidium cells at even higher temperatures, and thus maximize the optical density. We are also pursuing strategies to reduce time-of-flight broadening due to the finite transition time of the atoms through the beam. This will result in longer-lasting coherence and thus larger transparency and slower light. We are also interested in stopping light for on-chip memories, and exploiting the prolonged light–matter interaction in the waveguide for nonlinear optics at the few-photon level.

INTERVIEW BY RACHEL WON

Holger Schmidt and co-workers have a Letter describing their on-chip slow light on page 776 of this issue.

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