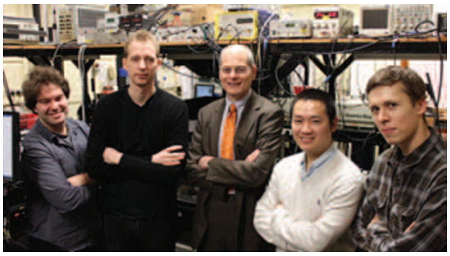
Hollow memories

A hollow-core optical fibre filled with warm caesium atoms can temporarily store the properties of photons. Michael Sprague from the University of Oxford, UK, explains to *Nature Photonics* how this optical memory could be a useful building block for fibre-based quantum optics.

Why did you decide to make an optical memory using a fibre-based architecture?
In general, a waveguide structure is beneficial because it can enhance the interaction between light and matter by confining light to a small beam cross-section and thereby lower the pulse energy required for an optical memory to operate. Consider our memory, for example; we can operate it using control field pulse energies of tens of picojoules, which are much smaller than the several nanojoules that a comparable free-space memory would require. In addition, a fibre-based memory can simplify the optical interaction by confining several optical beams in the same spatial mode. Using fibres also provides a realistic way to construct a large array of such memories. The choice of using hollow-core fibres is attractive for a couple of reasons. First, hollow-core fibres have a low optical loss (on the order of 1 dB m^{-1}). Second, their design is quite flexible and they can have large core diameters, which can both facilitate the loading of a sufficiently large number of atoms and also support relatively large optical modes. These features help to lengthen the storage time of our memory. The kagome fibres that we used were designed and drawn by Amir Abdolvand — a postdoctoral fellow in Philip Russell's group at the Max Planck Institute in Erlangen, Germany — and the experiments were performed here in Oxford, UK.

How does your memory work?
The idea is that you have an optical mode that you want to map to an atomic mode, store temporarily and then read out again a few nanoseconds later. We do this using a detuned Raman interaction between light and a warm vapour of caesium atoms inside a hollow fibre. The efficiency of the process is controlled by the Raman coupling constant. It's a dimensionless quantity that depends on several parameters, including the optical depth (defined as the on-resonance absorption of the transition), which in turn depends on how many atoms there are in the interaction. Other important parameters are the Rabi frequency of the interaction, the detuning of the pulses from resonance and the bandwidth of the optical pulse. We try to adjust these quantities to obtain a Raman coupling coefficient on the order of 1, which is required to make an efficient memory.



MEGAN ENGEL

The members of the Oxford University team in their laboratory. From left to right: Josh Nunn, Michael Sprague, Ian Walmsley, Xian-Min Jin and Krzysztof Kaczmarek. The Oxford group worked with researchers from the Max Planck Institute for the Science of Light in Erlangen, Germany, to build a fibre-based quantum memory.

Was it hard to make?
We experienced two main challenges when developing an optical memory in a hollow-core fibre. The first was to load a sufficient number of atoms into the fibre core. Our approach was to use a specially designed kagome fibre whose core area is ten times larger than that of usual photonic crystal hollow-core fibres. We also used a laser to 'blast' the atoms off the inner surface of the fibre, a technique pioneered by Alex Gaeta at Cornell University in the USA. By employing both these approaches, we were able to increase the number of atoms in the interaction to a level where we could operate the memory.

A second challenge was the short transit times of the warm atoms as they traversed the diameter of the fibre core. The storage and retrieval processes must be completed during this period. Atoms can lose their spin coherence through bouncing off the fibre walls. We overcame this limitation by using a Raman scheme that is compatible with short subnanosecond optical pulses and also by employing a larger-core kagome fibre. This gave us transit times of the order of 100 ns.

What applications do you foresee?
From our perspective, the broad bandwidth (1 GHz) of the memory is an exciting feature, particularly for applications related to quantum information processing. This is important because many memories operate with megahertz bandwidths, which are difficult to interface with existing single-photon sources that rely on spontaneous parametric downconversion. Our memory could be useful for synchronizing quantum information processing tasks in local networks. For example, many single-photon sources are inherently probabilistic — the generation of a single photon occurs rarely and at random intervals. Using our fibre-based quantum memory, we could store the output from an array of single-photon sources in order to have a way of gathering a large number of single photons in the same mode at the same time. This would be useful for realizing large-scale entanglement and performing a variety of quantum-enhanced information tasks.

How could your memory be improved?
There are several possible areas for improvement. The memory efficiency could be enhanced by pulse shaping or changing the direction of the retrieved pulse relative to the stored pulse. The memory lifetime is currently around 30 ns; with some modifications, we should be able to increase this to about 100 ns, which is the transit time of the atoms. We will probably need a larger diameter to attain longer storage times than this. We also have some ideas for reducing the memory noise level by actively suppressing the four-wave-mixing interaction.

What are your future plans?
We would like to store a true single photon, rather than an attenuated coherent state, which we've done to date. We are also very interested in exploring nonlinear interactions in hollow-core fibres. Lastly, there are some interesting technical challenges involved in splicing these hollow-core fibres to produce standard solid-core, single-mode fibres.

INTERVIEW BY OLIVER GRAYDON

Michael Sprague and co-workers have a Letter reporting a quantum optical memory made from a hollow-core fibre on page 287 of this issue.