located at the outskirts of the Brillouin zone. They are commonly referred to as the X and Y valleys.

Electrons from donors are distributed among the available states in both valleys by adhering to Pauli's exclusion principle and occupying states with lowest energy first. As a consequence of the in-plane crystal symmetry, the depths of both valleys are equal in a pristine, unstrained AlAs layer and the valleys end up equally populated (see Fig. 1). However, the authors devised an ingeniously simple but effective method to tune the population difference between both valleys. The sample is rigidly mounted on a piezo-actuator. At the turn of a voltage knob the piezo-actuator stretches and transfers part of its dilatation to the AlAs crystal. It breaks the in-plane symmetry of the crystal and concomitantly of the conduction-band topography. One valley is lifted in altitude with respect to the other. The total number of electrons remains fixed, but some spill over into the energetically favourable states of the now lower-lying valley. Under appropriate conditions, the upper valley can even be entirely emptied, such that a population difference, or so-called valley polarization, of 100% is achievable.

The rest is a straightforward extension of previous transport studies. Temperature-dependent resistivity measurements distinguish between metallic or insulating behaviour as the valley polarization is tuned. The outcome convincingly establishes a remarkable equivalence. Electrons reside in valley X or Y. This discrete degree of freedom plays a role in the metal–insulator transition problem entirely analogous to the electron-spin degree of freedom. The 2D layer is metallic when the valleys are equally populated or spin polarization is absent, whereas it becomes insulating when valley and spin polarizations are sufficiently large. These similarities leave little doubt that a common cause triggers the metal–insulator transition on polarizing spin or valley. Does this corroborate the screening argument? Although other interaction-based pictures are not obviously transferable to the valley degree of freedom, the screening model qualitatively accounts for the analogy. Valley polarization curtails screening in the same way that spin polarization does. It reduces the density of states and alters the Fermi wave vector in an identical manner.

Even so, the valley experiments do not necessarily disqualify other interaction scenarios. Thermodynamic properties such as the specific heat and the magnetic susceptibility could divulge clues that exclude other models, but their direct measurement is challenging because of the minute number of electrons involved. The true ground state at absolute zero remains mysterious. Phase-coherent localization may re-emerge at lower temperatures and convert the layer back into an insulator. Laboratories should gear up for experiments at ever-lower temperatures to address the profound question whether a 2D metal can survive close to absolute zero. The toolbox to do so has just been extended.

References

1. Gunawan, O. *et al. Nature Phys.* **3,** 388–391 (2007).
2. Abrahams, E., Anderson, P. W., Licciardello, D. C. & Ramakrishnan, T. V. *Phys. Rev. Lett.* **42,** 673–676 (1979).
3. Kravchenko, S. V., Kravchenko, G. V., Furneaux, J. E., Pudalov, V. M. & D'Iorio, M. *Phys. Rev. B* **50,** 8039–8042 (1994).
4. Abrahams, E., Kravchenko, S. V. & Sarachik, M. P. *Rev. Mod. Phys.* **73,** 251–266 (2001).
5. Finkel'shtein, A. M. *Sov. Phys. JETP* **57,** 97–108 (1983).
6. Dobrosavljevic, V., Abrahams, E., Miranda, E. & Chakravarty, S. *Phys. Rev. Lett.* **79,** 455–458 (1997).
7. Simonian, S., Kravchenko, S. V., Sarachik, M. P. & Pudalov, V. M. *Phys. Rev. Lett.* **79,** 2304–2307 (1997).
8. Das Sarma, S. & Hwang, E. H. *Solid State Comm.* **135,** 579–590 (2005).
9. Ilani, S., Yacoby, A., Mahalu, D. & Shtrikman, H. *Science* **292,** 1354–1357 (2004).

SLOW LIGHT

Dynamic photon storage

A scheme for dynamically tuning the coupling between a series of resonators and waveguides provides a means of storing light on an integrated photonic chip for longer than is possible with conventional slow-light systems.

Mehmet Fatih Yanik[1] and Shanhui Fan[2]

are in [1]the Department of Electrical Engineering and Computer Science, Massachusetts Institute of Technology, 77 Massachusetts Ave., Cambridge, Massachusetts 02139, USA.
[2]the Ginzton Laboratory, Stanford University, Stanford, Calofornia 94305, USA.
e-mail: yanik@mit.edu

Light has been the workhorse of modern telecommunications since the invention of fibre optics. The ever-increasing demand to be able to transmit information not only over the large distances between continents but increasingly over the much smaller distances such as the interconnects between high-speed microchips, has led to a variety of approaches to manipulating light. Despite this, no one has yet developed an effective means of storing a train of optical pulses without first converting them into electronic signals and then back again. This lack of so-called optical buffer presents a serious limitation for the development of optical transmission and processing systems. But on page 406 of this issue, Xu and colleagues describe a potential solution[1]. By actively controlling the passage of light between optical waveguides and optical resonators[2,3], they demonstrate a means of capturing light in a way that overcomes the fundamental limits that have hindered the development of other approaches.

At first glance, one might expect that it should be possible to construct an optical buffer by trapping light in a conventional optical resonator. Unfortunately, the trapping time of any such resonator is inversely proportional to the speed with which light pulses can be injected into it, according to a relation known as the delay–bandwidth product. This fundamentally dictates that a bit of information cannot be stored for longer than the temporal length of the bit. The only way to improve the storage capacity of such an approach is to use a cascade of many resonators. However, the large number of resonators that this requires to reach the sort of delay demanded by most telecommunication applications, limits the feasibility of doing so in practice.

Some improvement to the delay–bandwidth product can be achieved by a more sophisticated approach that involves transferring the information contained in a string of optical pulses to the electronic states of a coherent ensemble of atoms — such as an ultracold gas or similar system[4–6]. This enables a light pulse to be stored for durations as long as 50 pulse lengths[7]. But here too, restrictions on the wavelengths and conditions under which these systems operate limit them from becoming a storage solution that can be integrated with on-chip photonic devices.

The solution demonstrated by Xu *et al.*[1], circumvents the delay–bandwidth problem altogether, by taking a dynamic approach[2,3,8] to trap light. Their system consists of two dynamic resonators coupled to two waveguides (Fig. 1a) patterned in silicon. The resonators are designed such that they are initially out of resonance with each other, which couples them to the waveguide and allows light to flow back and forth between them and the waveguide unhindered (Fig. 1b). But when one resonator is tuned into resonance with the other, both become isolated from the waveguide. If any part of a pulse travelling through the system finds itself between the two resonators while this happens, that part of the pulse gets trapped between the resonators (any part that lies on either side of the resonators gets reflected). Subsequent detuning of the second resonator from the first re-couples the resonators to the waveguide, which releases the trapped pulse (Fig. 1d). The captured pulse can be held long enough to exceed the constraints of the delay–bandwidth product imposed on the passive all-optical approaches.

The main challenge to realizing such a dynamic optical buffer is the speed at which it must be switched in order to capture light pulses. To capture an incoming pulse on a chip-scale device, it must be possible to switch the device on and off at speeds faster than the transit time of the pulse. There are many optical phenomena that enable high-speed modulation, yet changing the bandwidth of a system with large contrast at high speeds is not an easy task[2,3,8]. In the present work, this is achieved by illuminating each resonator with a control pulse that generates free carriers in the silicon, which alters silicon's refractive index and shifts the frequencies of resonators[8].

The device demonstrated by Xu *et al.* does have some important limitations, though. Most obviously, because it captures only a section of any pulse passing through the system when it is switched into resonance, the shape of the subsequently released pulse is solely determined by the release process. Consequently, any information that is encoded in the shape of the original pulse is lost. Moreover, ensuring that the system is switched at just the right moment when a pulse is in between its resonators requires precise timing in tuning resonators. However, these issues can be overcome by using multiple dynamic storage units coupled to waveguides with low group velocities that slow the speed of light and pre-compress the pulses before trapping[2,3].

The greatest challenge in practice will probably be in achieving long buffering times. Owing to the large optical losses in the on-chip resonators and the free-carrier absorption, the storage time of the current device is limited to less than 100 ps. On-chip passive resonator storage times of several nanoseconds long has been demonstrated[9], which could enable delays of many optical bits long, and shortening the pulse length[10] of each bit may improve this further. Furthermore, introducing optical gain into the system could help compensate for optical losses.

A significant advantage of using dynamic photonic structures over coherent electronic states is the orders of magnitude improvement in bandwidths, as well as much greater freedom in the choice of operating wavelengths, at the expense of buffering times[2]. For telecommunication systems and also for rapidly decohering quantum systems, bandwidth (which sets the bit rate) is more critical than the duration of buffering.

Another challenge in the authors' approach is related to one of its strengths — that in storing quantum states of light. For this purpose, storing

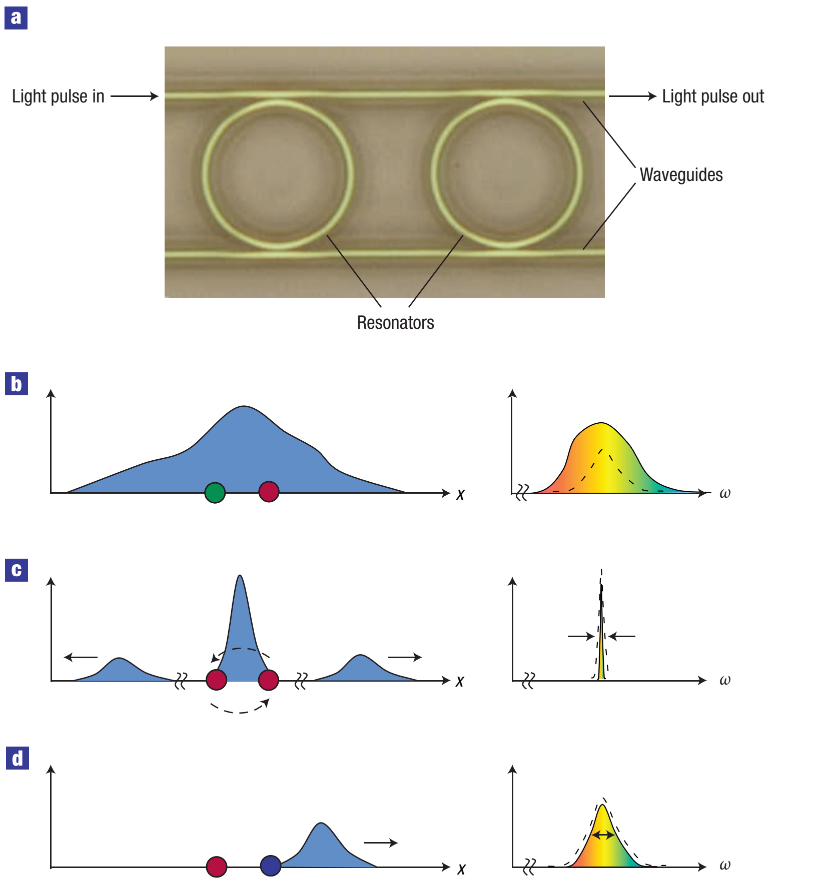


Figure 1 Capturing light by dynamic tuning. **a**, Micrograph of the system demonstrated by Xu *et al.*[1], which consists of two circular optical resonators coupled by two straight waveguides on a silicon chip (reprinted from ref. 1). **b–d**, Left: Distribution of light intensities along the device where the two resonators are represented by the two coloured circles. Right: Frequency spectrum of the pulse in the resonator (solid line); the bandwidth of the resonator (dashed line, right) under different resonance conditions. **b**, The resonators are initially out of resonance with each other, which causes them to be strongly coupled to the waveguides, to exhibit a large bandwidth, and to enable an initially wide pulse to be distributed across the whole system. **c**, Tuning the first resonator into resonance with the second decouples both from the waveguide, which traps part of the pulse between them and compresses its bandwidth. **d**, Tuning the second resonator out of resonance with the first re-couples them to the waveguide, enabling the pulse to be released while broadening the pulse bandwidth during this process.

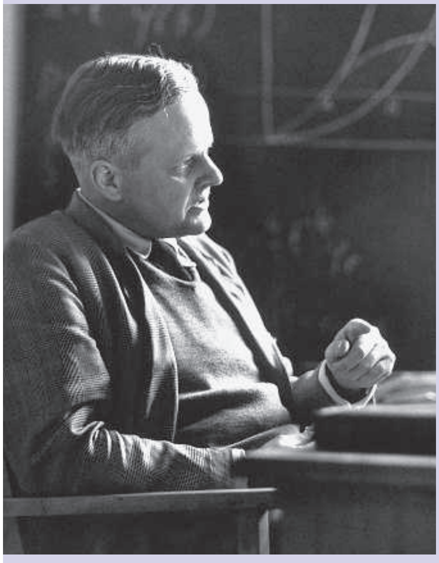
optical information by the conventional approaches of converting it to and from electronic signals is simply out of the question. Although neither the preservation of quantum coherence nor the shape of an input pulse is demonstrated by Xu *et al.*, on-chip phase-coherent light storage is in principle possible using such dynamic approaches[2,3]. But in the near-term, the greatest contribution of the present work will probably be towards realization of practical on-chip optical memory elements.

References

1. Xu, Q. F., Dong, P. & Lipson, M. *Nature Phys.* **3,** 406–410 (2007).
2. Yanik, M. F. & Fan, S. *Phys. Rev. Lett.* **92,** 083901 (2004).
3. Yanik, M. F., Suh, W.,Wang, Z. & Fan, S. *Phys. Rev. Lett.* **93**, 233903 (2004).
4. Liu, C., Dutton, Z., Behroozi, C. H. & Hau, L. V. *Nature* **409,** 490–493 (2001).
5. Phillips, D. F., Fleischhauer, A., Mair, A., Walsworth, R. L. & Lukin, M. D. *Phys. Rev. Lett.* **86,** 783–786 (2001).
6. Bigelow, M. S., Lepeshkin, N. N. & Boyd, R.W. *Science* **301,** 200–202 (2003).
7. Camacho, R. M., Pack, M. V. & Howell, J. C. *Phys. Rev. A* **73,** 063812 (2006).
8. Xu, Q. *et al. Phys. Rev. Lett.* **96,** 123901 (2006).
9. Vahala, K. J. *Nature* **424,** 839–846 (2003).
10. Altug, H., Englund, D. & Vuckovic, J. *Nature Phys.* **2,** 484–488 (2006).

CARL VON WEIZSÄCKER

A man for all seasons



GETTY

In his native Germany, Carl Friedrich von Weizsäcker was feted as the last of a breed long considered extinct in the Anglo–Saxon world: that of the *Universalgelehrter*, the polymath who roams freely across disparate fields of thought. Certainly, no *curriculum vitae* encapsulates better the intimate, fluid and often troubled relations between science, philosophy and politics in twentieth-century Germany than his. A protégé of Werner Heisenberg, he counted the Dalai Lama among his own students. He was asked to run as German president in 1979 — that office was later held by his younger brother Richard. A committed pacifist after the war, he had worked on Hitler's atom bomb.

Von Weizsäcker was born in the northern port city of Kiel in 1912. His luck, or fate, was to come of age in the Germany of the late 1920s, just as Heisenberg, Niels Bohr and others were fleshing out the bones of quantum mechanics. This was revolutionary physics that also challenged the fundament of classical philosophy. In von Weizsäcker's own words, "I studied physics out of philosophical interest, and I pursued philosophy as a consequence of my reflections on physics; my interest in politics, on the other hand, stems from a sense of duty".

His early contributions to nuclear physics and astrophysics, as yet uninfluenced by politics, were unimpeachable. The semi-empirical formula for nuclear binding energy, still familiar in undergraduate physics courses, bears his name and that of Hans Bethe; in 1937, he and Bethe sketched out the series of nuclear reactions catalysed by carbon, oxygen and nitrogen by which the Sun fuses hydrogen to helium. In 1944, he was the first to propose that the planets formed in a disk of gas and dust around the Sun.

But a physicist of von Weizsäcker's stamp could not long remain divorced from politics. Unlike Bethe and others, whom the gathering storm forced onto the path of emigration from 1930s Germany, von Weizsäcker stayed put, moving, in 1942, from Berlin to the University of Strasbourg in occupied Alsace. His wartime involvement in the Nazi bomb project remains controversial. He accompanied Heisenberg, then head of the bomb effort, on his visit to Niels Bohr in Copenhagen in 1941, shortly before Bohr was spirited away to Los Alamos to work on the US bomb. The true purpose of that visit remains hotly debated, not least since Michael Frayn's 1998 stage-play *Copenhagen*.

Von Weizsäcker's claim that the German bomb never materialized not because he and his collaborators could not — which was undoubtedly true, given the limited resources at their disposal — but rather because they would not, remained the accepted version of events for almost half a century. Only with the publication in 1993 of conversations between the German scientists, taped secretly in the British internment camp at Farm Hall near Cambridge towards the end of the war, was the whitewash of this self-absolution exposed.

Whatever his wartime role, von Weizsäcker's commitment to the pacifist cause in the years following the war is indubitable. He was the initiator of the 1957 Göttingen declaration, in which 18 prominent physicists spoke out against West Germany developing an independent nuclear deterrent, and called for the production of nuclear weapons worldwide to be halted. In the following decades, he remained one of Germany's most prominent and authoritative pacifist voices, constantly formulating alternatives to the cold-war world-order and, when that era had ended, leading the scientific outcry against France's renewed nuclear testing in the mid 1990s.

Always a committed Christian, von Weizsäcker's own work tended ever more towards the attempt to unify scientific and religious philosophy in one overarching structure. But the attempt to find an all-embracing *Weltformel* defeated him, as it had Heisenberg and Albert Einstein before him. In 1970, he founded an institute in Starnberg near Munich, later the Max Planck Institute for Social Sciences, to study sources of conflict in a world dominated by science and technology. From there, he wrote prolifically on an unparalleled range of topics in physics and philosophy, on the relationship of the developed and the developing worlds, on environmental destruction, and on the marriage of eastern mysticism and western science.

One of the last surviving protagonists of a turbulent period of scientific and political history, Carl Friedrich von Weizsäcker died near Starnberg on 29 April 2007, aged 94.

Richard Webb
Richard Webb is a News & Views editor for Nature.