Simply silicon

Silicon integrated optical chips that can generate, modulate, process and detect light signals offer the tantalizing prospect of cost-effectively meeting the ever-increasing demands on data speed and bandwidth.

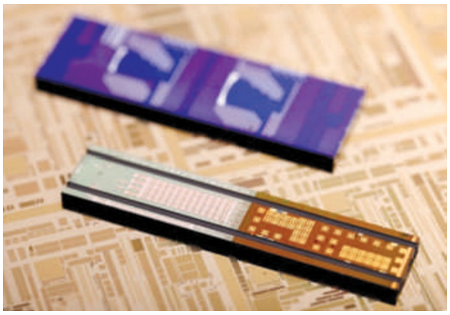
Microelectronic chips made from silicon are cheap and easy to mass-fabricate, and can be densely integrated. It is no surprise, therefore, that researchers in the photonics sector have strived for years to create silicon-based optical devices that can exploit the benefits of silicon while also being fully compatible with electronics.

This issue of *Nature Photonics* has a special focus on silicon photonics. It features a collection of three Review Articles and one Progress Article on the latest developments of various active silicon optoelectronic devices, as well as two Commentaries on emerging topics of importance such as mid-infrared silicon photonics and the economic challenges currently facing the field.

In addition, on page 498 we have an interview with Mario Paniccia, director of the Photonics Technology Lab of Intel, who discusses some of the firm's latest silicon photonics news. Paniccia describes Intel's recent unveiling of its high-speed (50 Gbit s^{-1}) optical data communication link based on two integrated silicon optical chips, and how this development is going to introduce high-speed, low-cost optical data transmission to the world of computers[1].

In terms of individual components, the silicon laser — arguably the most important active photonic device among them all — is actually one of the most challenging to realize. This is because silicon has an indirect bandgap that prohibits spontaneous emission and thus impedes lasing. However, the past few years have seen a rapid expansion of research in this field, as reviewed by Di Liang and John E. Bowers on page 511[2]. The successful examples of silicon lasing discussed in their Review — silicon Raman lasers, germanium-on-silicon lasers and hybrid silicon microring and microdisk lasers — demonstrate the feasibility of silicon lasers and the challenge that these technologies pose to the currently dominant conventional semiconductor lasers based on direct bandgap compound semiconductors such as GaAs and InP.

Another crucial device is the on-chip optical modulator — the driving force of optical interconnects. Unfortunately, the centrosymmetric crystal structure of silicon does not exhibit the Pockels effect (a linear electro-optical effect), thus making electro-optic silicon modulators difficult to realize. On page 518, Graham Reed *et al.* review the state-of-the-art technology in the field of silicon modulators, and describe the candidate solutions of the future[3].



© 2010 INTOUCHSTUDIOS.COM

The use of on-chip photodetectors for detecting optical signals is also important. On page 527, Jurgen Michel *et al.* describe how epitaxial growth of germanium on silicon is showing great promise, and review high-performance germanium-on-silicon photodetectors and avalanche photodetectors[4].

A new area of research is the exploitation of the strong nonlinearities of silicon to create active on-chip optical devices. On page 535, Juerg Leuthold *et al.* detail the different types of nonlinearities in silicon, including self-phase modulation, third-harmonic generation, stimulated Raman scattering, four-wave mixing and cross-phase modulation, and review the key applications of such nonlinearities in optical signals generation, amplification, processing and sensing[5].

The low-loss mechanism of fibre-optic communications systems has meant that most research in silicon photonics has surrounded the telecommunications wavelength of 1,550 nm, with little attention being paid to the mid-infrared region. However, silicon can be a good material for mid-infrared wavelengths owing to its inherent transparency and strong nonlinear optical effects in this wavelength region. On page 495, Richard Soref describes the design of active and passive components that operate in the mid-infrared, and also outlines some of their potential applications[6].

Coincidentally, two of the research papers published in this issue also fall within the emerging fields of nonlinear and mid-infrared silicon photonics. On page 557, Xiaoping Liu *et al.* from Columbia University and IBM in the USA demonstrate a mid-infrared silicon optical parametric amplifier by taking advantage of the absorption reduction at wavelengths approaching the two-photon absorption bandedge of 2,200 nm (ref. 7). On page 561, Sanja Zlatanovic *et al.* describe how they have exploited four-wave mixing in silicon waveguides in the spectral region beyond 2 μm to generate mid-infrared light at 2,388 nm over a bandwidth of 630 nm on a single silicon chip[8]. As Bahram Jalali explains in his News & Views article on page 506, both research findings open the door to nonlinear silicon photonics in the mid-infrared by providing mid-infrared sources and amplifiers unachievable through other means, with potential benefits for biochemical sensing and medical therapy applications[9].

Although the continued development of new optical devices based on the silicon platform is undoubtedly a cause for celebration, perhaps now is the ideal time to copy the electronics industry in the establishment of schemes that can share the costs of making test samples, facilitate test runs and propel research progress into more complex integrated chip-scale photonics. This is the main call from Michael Hochberg and Tom Baehr-Jones on page 492 of this issue[10].

The integrated silicon optical chip, together with its long-awaited impact on photonics, may be closer than we think. ❐

References

1. Won, R. *Nature Photon.* **4,** 498–499 (2010).
2. Liang, D. & Bowers, J. E. *Nature Photon.* **4,** 511–517 (2010).
3. Reed, G. T., Mashanovich, G., Gardes, F. Y. & Thomson, D. J. *Nature Photon.* **4,** 518–526 (2010).
4. Michel, J., Liu, J. & Kimerling, L. C. *Nature Photon.* **4,** 527–534 (2010).
5. Leuthold, J., Koos, C. & Freude, W. *Nature Photon.* **4,** 535–544 (2010).
6. Soref, R. *Nature Photon.* **4,** 495–497 (2010).
7. Liu, X. Osgood, R. M. Jr, Vlasov, Y. A., Green, W. M. J. *Nature Photon.* **4,** 557–560 (2010).
8. Zlatanovic, S. *et al. Nature Photon.* **4,** 561–564 (2010).
9. Jalali, B. *Nature Photon.* **4,** 506–508 (2010).
10. Hochberg, M. & Baehr-Jones, T. *Nature Photon.* **4,** 492–494 (2010).