silicon microring modulator, which has a 78 μm^2 footprint on a silicon-on-insulator substrate[11]. The plasmonic phase modulator was demonstrated at an operation speed of 40 Gbit s^{-1}; its modulation frequency response was flat beyond 65 GHz. The modulator functioned over a 120-nm-wide wavelength range centred at 1,550 nm. This indicates that the modulator can be used at most telecommunication wavelength regions in the optical S (1,460–1,530 nm), C (1,530–1,565 nm) and L (1,565–1,625 nm) bands. The proposed surface-plasmon modulator exhibited superior performance in terms of speed and wavelength range compared with other reported plasmonic modulators. The plasmonic modulator was found to be thermally stable for operation temperatures up to 85 °C.

In summary, Melikyan and colleagues have demonstrated a compact, high-speed, electro-optic modulator that employs surface-plasmon waves. It functions at telecommunication wavelengths and has a wide operating wavelength range. By integrating this modulation device with other key elements (such as nanolasers, plasmonic waveguides and detectors), chip-scale optoelectronic integrated circuits that employ surface-plasmon waves should become available in the near future. ❐

Min-Hsiung Shih is at the Research Center for Applied Sciences (RCAS), Academia Sinica, 128 Academia Road, Section 2, Nankang, Taipei 115, Taiwan and the Department of Photonics, National Chiao Tung University, 1001 Ta Hsueh Road, Hsinchu 300, Taiwan.
e-mail: mhshih@gate.sinica.edu.tw

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OPTICAL MATERIALS

Nanostructured paper

Finding a substrate material for solar cells that simultaneously provides a high optical transparency and a high transmission haze (so that any transmitted light will scatter diffusively) is challenging. It now appears that an engineered paper could be an ideal substrate. Zhiqiang Fang and co-workers from the USA and China have developed a wood-fibre-based nanostructured paper that provides a transparency of ~96% and a haze of ~60% (*Nano Lett.* **14,** 765–773; 2014). This material is potentially useful for photovoltaics, where it could reduce the angular dependence of light harvesting for solar cells, and it could also benefit outdoor displays by reducing glare and specular reflections of sunlight.

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The team produced the transparent paper by using an oxidation process called TEMPO to introduce carboxyl groups into the cellulose fibres of wood. This process weakens the hydrogen bonds between the cellulose fibrils, causing the wood fibres to swell. The result is a paper with a much higher packing density than usual and greatly improved optical transparency and haze.

Analysis by scanning electron microscopy revealed that the transparent paper has a homogenous surface as a result of voids being filled by small fibre fragments. In the spectral range of 400–1,100 nm, the transparent paper had a transmittance of ~96% and a transmission haze of ~60%.

The benefits of the enhanced haze of the transparent paper for photovoltaic devices were demonstrated by laminating the paper to the top of an organic solar cell and measuring the cell's photocurrent as a function of the incident angle of white light. The measured photocurrents exceeded those of a control device that did not have the transparent paper for angles larger than 7° and for incident angles between 60° and 87°; improvements in the photocurrent of up to 15% were observed. The paper layer increased the power conversion efficiency of the solar cells by 10% (from 5.34% to 5.88%).

Fang explained that the improvements "can be explained by two factors: the reduced reflection of the light due to the low index contrast between the top layer of the photovoltaic device and the transparent paper, and the directional change of the incident light in the transparent paper."

NORIAKI HORIUCHI