drying process results in a MWNT morphology (entangled bundles 50 nm in diameter) that creates surface roughness. The researchers used scanning force microscopy to characterize the adhesive behavior of the foot-hair mimics and said that the disordered and entangled MWNT bundles provide penetration space for the probe. Higher penetration depths and adhesion forces were observed for this morphology than for MWNTs aligned vertically and densely packed or lying flat on the surface.

The researchers said that any pattern of MWNTs on silicon, which can be controlled by photolithography, can be precisely transferred onto a polymer surface. Furthermore, elastomeric polymers can take the place of the glassy PMMA and provide flexibility on different length scales. In addition, the researchers said that "this approach can provide excellent candidates for dry adhesives for microelectronics and space applications."

STEVEN TROHALAKI

Optical Control of THz Reflectivity of High-Resistivity Semiconductors Achieved

L. Fekete, J.Y. Hlinka, F. Kadlec, and P. Kuzel from the Institute of Physics, Prague, Czech Republic, and P. Mounaix from the Centre de Physique Moléculaire, Optique et Hertzienne, Talence, France, have achieved good modulation of the reflected terahertz wave (reflectivity R = 3–85%) in GaAs by means of optical pumping of the semiconductor. In a report published in the August 1 issue of *Optics Letters* (p. 1992), the researchers said that their finding can be useful in applications such as all-optical devices that allow transfer of information from the optical spectral band to the THz band, opto-THz switches, and modulators. In their ground state, high-resistivity semiconductors are transparent and virtually dispersion-free for THz radiation. However, photoexcited semiconductors exhibit a strong interaction with THz light mediated by free carriers. Fine tuning of the strength of the interaction by the intensity and/or wavelength of optical excitation then leads to interesting phenomena that are directly utilizable for THz light modulation and switching.

The scientists used high-resistivity semiconductor (GaAs and Si) wafers as samples. In their experiments, a Ti:sapphire multipass optical amplifier delivered 1 mJ light pulses with a duration of 55 fs and a mean wavelength of 810 nm at a repetition rate of 1 kHz. One part of the beam (pump) was used for the excitation of the sample surface. Another part of the beam was used for the generation and detection of broadband THz (probe) pulses. The THz pulse, generated at a separate sample, was incident on and transmitted through the GaAs or Si sample under test. The pump pulse was allowed to be incident upon the entrance face of the sample after the THz pulse had entered the sample, but while it was still completely inside the sample. A fraction of the THz pulse was reflected at the exit face of the sample and then propagated back to the entrance face, where a fraction was again reflected back toward the exit face. The transmitted THz signal then consisted of the initial transmitted pulse as well as the echo arising from the reflection at the entrance face. The internal THz reflectance on the photoexcited surface (entrance face) depended dramatically on the excited layer thickness (controlled by the wavelength of the optical pump pulse) and on its conductivity (controlled by the pump pulse intensity). An analytical model was used to explain the experimental result.

VIVEK RANJAN

Extended Low-Temperature Plasma-Assisted Bonding Enhances Wafer Bonding Strength Uniformity

In a plasma-assisted low-temperature Si/Si wafer bonding process, a major concern is how to avoid voids at the bonding interface and improve bonding strength. However, when using

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conventional infrared (IR) imaging of a bonded wafer, it is difficult to determine whether a lack of visible voids on the interface corresponds to strong bonding. Using dynamic surface energy measurement, researchers Xuanxiong Zhang of Shanghai Research Center for Wireless Communication in China and Jean-Pierre Raskin of Université Catholique de Louvain in Belgium have studied bonding strength and bonding uniformity of bonded wafer pairs before and after post-bonding annealing. Low-temperature O_2 plasma exposure was used to bond Si samples (3 in. diameter, <100>-oriented, *p*-type, 15–25 Ω cm) that had been pre-cleaned using a standard procedure and then exposed to O_2 plasma for 5 s. The researchers discovered that, overall, the bonding strength increased significantly after 10 h of annealing at 120°C.

As the researchers reported in the August issue of *Electrochemical and Solid-State Letters* (p. G268; DOI: 10.1149/1.2012288), some areas seemingly free of voids in IR images have much lower surface energy values than the mean value, indicating that these areas may be de-bonding or have voids. After 20 h of annealing, the overall bonding strength is improved further, but the non-uniformity observed earlier still exists. With longer annealing times of up to 120 h, the bonding strength rose further by a small amount, but the uniformity of the bonding strength is remarkably enhanced. In particular, in almost all tested samples, the bonding strength at the rim of a bonded pair is higher than in the center of the bonded pair.

The researchers believe that the increase of bonding strength and the enhancement of bonding strength uniformity over the annealing time may be due to out-diffusion of bonding by-products (i.e., hydrogen, oxygen, and water vapor). Therefore, they conclude that extended post-bonding annealing is necessary to obtain uniform bonding strength on the whole wafer level and improve the percentage of successful bonding yield in practical applications.

SHIMING WU

Spa Water Used for the Fabrication of Visible-Light-Emitting Porous Silicon

Visible light emission from porous silicon has potential application in silicon-based optoelectronic devices. Most porous Si (p-Si) layers are prepared by anodic etching on *p*-type Si wafers or photoetching *p*-type Si wafers in an HF solution. Both methods have disadvantages involving either complicated fabrication steps or special handling of toxic chemicals. A group of researchers in Japan have now used potable spa water as the solution in photoetching to produce visible-light-emitting p-Si.

As reported in the August issue of *Electrochemical and Solid-State Letters* (p. G251; DOI: 10.1149/1.2001791), S. Adachi and K. Tomioka from the Department of Electronic Engineering of Gunma University in Japan have fabricated visible-light-emitting porous Si by photoetching Si in spa water. The spa water they used is a colorless alkaline solution from one of the Japanese hot springs, the Tenkeisen Spa. The researchers photoetched an *n*-type Si(111) wafer in the Tenkeisen Spa water (TeSW) under 5 mW He-Ne laser (632.8 nm) illumination for 3 h with a laser spot size of ~1 mm. They proposed that the photochemical etching in Si took place in a two-step reaction: first electron–hole pairs were generated in the Si by optical excitation. Hole aggregation near the Si–solution interface produced Si^{2+} ions; the ionic Si^{2+} then reacted with OH^- to form $Si_x(OH)_y$ complexes, which are soluble in the TeSW. The researchers also anodized a *p*-type Si(100) wafer in an ethanolic HF electrolyte for comparison. Both p-Si samples showed a red photoluminescence peak at 1.95 eV.

The structural and optical properties of the TeSW-prepared p-Si sample are nearly the same as those prepared in HF solution, although neither H^+ nor F^- is present in the spa water. The thick-

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