Researchers at the Tokyo Institute of Technology (Tokyo, Japan) have created a dual buffer technique that may enable new, large-scale integration (LSI) optical devices to be manufactured directly on silicon substrates.

The final objective, according to team leader Kazuo Shinozaki of Tokyo Institute of Technology (Tokyo, Japan), is a photonic system on silicon (Si) chips. “So far, our device is in a preliminary state but looks good,” he says. “It should be able to contain optical circuits and conventional LSI circuits on the same Si substrate in the near future.”

Electronic and optical circuits are typically handled by discrete devices, but Shinozaki says the objective of his team’s work is to “form an elemental optical circuit on an Si substrate. In particular, we aim to make an optical switch using electro-optic thin film.”

Heretofore, most research on thin-film electro-optic effect has been done on oxide single-crystal substrates, but that kind of substrate is too expensive and hard to mass-produce for commercialization, Shinozaki says. He and his collaborator, Kazuaki Kurihara of the Materials and Environmental Engineering Laboratories of Fujitsu Laboratory Ltd. (Kanagawa, Japan), and their research group grew Pb(Mg\(_{1/3}\)Nb\(_{2/3}\))O\(_3\)-PbTiO\(_3\) (PMN-PT) thin film on appropriate buffer layers laid down on an Si substrate so that the thin-film layer would not react with the Si substrate. “Buffer layers enable the growth of epitaxial thin films,” Shinozaki says, “and it can also control certain properties of the thin-film layer.”

The difference in crystalline structures and, therefore, molecular bonds between oxide thin films and Si substrates necessitates a buffer layer between the two to avoid creating an amorphous silicon-oxide layer that degrades optical device performance. The group used a cesium oxide/yttria stabilized zirconia (CeO\(_2\)/YSZ)-stacked buffer layer developed during oxide superconductor film research. They did so because YSZ is more thermodynamically stable than SiO\(_2\), an important characteristic for matching thin-film depositions in high-temperature Si manufacturing.

The team used pulsed laser deposition (PLD) to deposit two kinds of buffer layers: strontium ruthenium oxide (SRO), which consisted of SrRuO\(_3\)/(SrTiO\(_3\))/(STO)/ (La,Sr)CoO\(_3\)/CeO\(_2\)/YSZ; and lanthanum-strontium-cobalt-oxide (LSCO), which consisted of LSCO/CeO\(_2\)/YSZ. The team then laid PMN-PT thin films down on both buffer layers. On the LSCO layer, the thin film showed (001) orientation peaks, but showed other peaks as well. The thin film on the SRO layer showed only (001) diffraction peaks. The x-ray pole figure of PMN-PT thin film deposited on the SRO revealed that the film was epitaxially grown. “Both crystallinity and orientation of the thin film on the SRO was better than that on the LSCO,” Shinozaki says. “This is due to the smaller lattice mismatch between PMN-PT and the SRO buffer layers.”

The team found large differences in the electrical properties of PMN-PT thin films on the SRO and the LSCO. The film on the SRO, because of its columnar structure, showed high leakage current, however, they were able to reduce the leakage by depositing the PMN-PT in an environment of NO\(_2\) gas instead of O\(_2\) in the PLD chamber. Leakage of films deposited in NO\(_2\) is two magnitudes less than that of films deposited in O\(_2\).

The optical and electro-optic properties of PMN-PT thin film of 1.6-µm thickness deposited on an LSCO layer in an NO\(_2\) atmosphere were as follows: The optical light propagated into the thin film had < 3-dB/cm loss, and the...
refractive index of the thin film was 2.48 for light of 1.55 µm wavelength. Taking the higher correlation between composition and electro-optic properties near the MPB region into account, the PMN-PT thin film deposited on an Si substrate tended to show a lower electro-optic coefficient than that of a PMN-PT single crystal. Shinozaki says “this might relate to the residual stress in PMN-PT by the Si substrate. More precise experiments are necessary to fully understand the electro-optic properties of epitaxial thin films.”

Jeffery Cross of the Silicon Device Lab at Fujitsu Laboratories (Atsugi, Japan) says, “R&D on thin-film-based electro-optical switches has been going on worldwide for more than 20 years. With the explosive growth of the internet and increased telecommunications traffic, there has been renewed interest in electro-optical components such as modulators and switches based upon thin films. A great deal of work on growing electro-optical films has been done using relaxor ferroelectrics such as PMN-PT or pseudo-cubic PLZT. By growing the optical material on Si, processing and integration is simplified because of well-developed processes for Si wafers and ease of handling. In addition, cost of the substrate is reduced since Si wafers per unit area are much cheaper than single crystal-oxide substrates. Shinozaki’s group has demonstrated the possibility of producing thin-film electro-optic components such as electro-optic modulators and switches directly on Si, which would allow both cost reduction and ease of integration for future electro-optic components.”

—Charles Whipple

**New Metric Measures True Linewidth Roughness**

The ability to measure linewidth roughness on transistor gates during the manufacturing process is of critical importance to the semiconductor industry because it affects device performance. Linewidth roughness is currently universally measured by calculating the standard deviation of the measured widths, which measures a combination of the true roughness and a false “noise roughness.” However, the current metric is subject to significant bias error, which could cause the measured value to be off by 40% or more from the true value.

In a joint collaboration between the National Institute of Standards and Technology (NIST; Gaithersburg, MD) and SEMATECH (Austin, TX), researchers devised a new metric for measuring linewidth roughness, which removes bias error.

While the old method takes a single measurement using all of the available time, the group’s proposed alternative divides the available time into two or more equal parts, providing multiple measurements. The individual measurements are noisier than the single measurement of the existing method, “however, because we have several measurements, we can independently estimate the true roughness and the false noise roughness,” explains NIST project leader John Villarrubia. Because the new method, unlike the old one, allows a separate estimate of the noise roughness, a correction can be applied to each of the measurements. The measurements can then be averaged to produce a single roughness number.

The new algorithm applies to edge-roughness and width-roughness measurement, and it will find applications wherever the industry needs to measure roughness, such as in resists, photomasks, and interconnects. The most immediate application is for controlling transistor-gate roughness. —Phillip Espinasse

**Physics continued from page 6**

of future research will be to translate the mechanisms of superfluidity that scientists observe into the charged world of electrons.

He says that the Fermi gas, which has a density one billion times lower than a metal and in which the atoms are more easily controlled, acts as a sort of “model airplane” for studying the superconductors that interest scientists. “We want to use cold atoms and learn something about matter in general,” he says. “Suddenly we have a test bed. We have experimental tools and theoretical tools where we can put atoms together in novel ways.”

Thomas says the gases can also be a model for the behavior of atoms inside neutron stars and for the quark-gluon plasmas that dominated the early universe. As such, they could prove useful for astronomers and cosmologists trying to understand how the universe works.

—Neil Savage