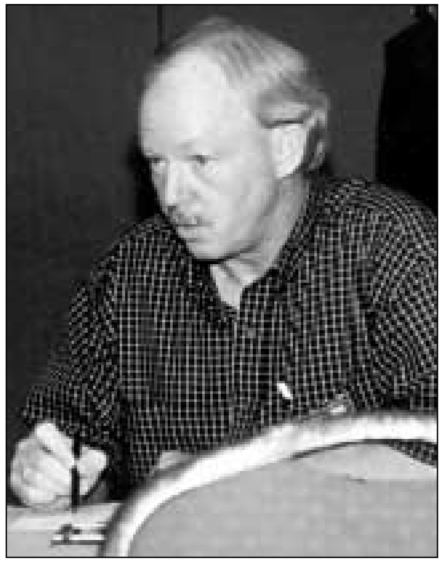
High-κ Gate Dielectric and Transparent Conducting Oxide Explored in MRS Workshops

High-κ Gate Dielectric: What, When, and How to Replace SiO_2

The first Materials Research Society Workshop on High-κ Gate Dielectrics was held June 1–2, 2000, in New Orleans. The workshop organizers, Glen Wilk (Bell Labs, Lucent Technologies), Veena Misra (North Carolina State University), and Eric Vogel (National Institute of Standards and Technology), designed the meeting to address a major roadblock in scaling metal-oxide semiconductor field-effect transistors (MOSFETs)—the gate dielectric. Most gate oxides, depending on the application, are rapidly approaching the sub-20-Å thickness regime, which has led to severe concerns about leakage (off-state) current, threshold voltage control, and long-term reliability.

Approximately 80 attendees participated, representing industry (IC companies), academia, national laboratories, and tool vendors. Both days of the meeting focused on the critical issues and properties required for the successful insertion of a high-κ dielectric to replace SiO_2 for scaled transistors in complementary metal-oxide semiconductor (CMOS) technology. The workshop format also featured a panel discussion on each day, which all of the speakers attended. All of the 18 speakers were invited, ensuring insightful presentations with the latest results from the leaders in the field.

The relative immaturity of the field, coupled with the urgent and rapidly approaching need to introduce a new material into production, was evident, as the reported results ranged from fundamental materials properties to full transistor device characteristics. The most heavily studied materials were the Group III and Group IV metal oxides (e.g., Al_2O_3, La_2O_3 , ZrO_2, and HfO_2, and combinations thereof) and their silicate analogues (e.g., La-Si-O and Zr-Si-O systems), deposited by methods including sputtering, chemical vapor deposition, and molecular-beam epitaxy. The best film morphology is still not clear, as several presentations showed very good electrical results by maintaining amorphous dielectric films, while others showed very encouraging results from polycrystalline and single-crystal films. Most researchers demonstrated equivalent oxide thicknesses (t_{ox}) of less than 15 Å, and several demonstrated thicknesses of under 10 Å (i.e., the films displayed the electrical performance that 15 Å or 10 Å of pure SiO_2 would show). As was mentioned throughout the meeting, however, great care must be taken to accurately assess performance, as many of these high-κ materials exhibit significant undesirable characteristics that SiO_2 does not, such as dielectric relaxation and chemical instabilities under thermal processing.



At the MRS ***High-κ Gate Dielectric Workshop****, invited speaker* ***Angus Kingon*** *(North Carolina State University) addressed the processing and properties issues for La_2O_3-SiO_2 and HfO_2-SiO_2 systems in gate stack applications.*

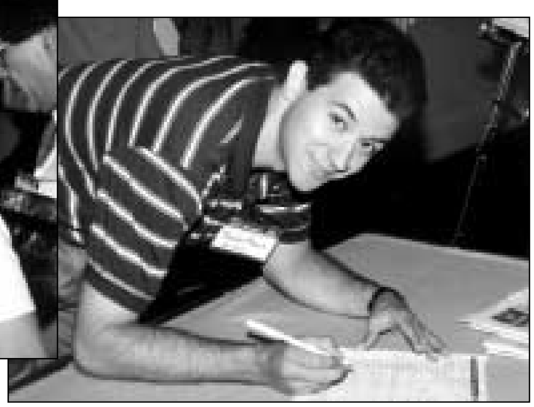
Several main points regarding high-κ materials emerged from the panel discussions:

(1) The interface with the Si substrate must be of extremely high quality in order to continue improving device performance. Ideally, it would be as good as or better than that of SiO_2.

(2) Nearly all of the high-κ gate dielectrics reported thus far show a significant flatband voltage shift possibly from fixed charge, (the origin of which is not yet known), resulting in problems with turning on the devices.

(3) The choice of gate electrode material remains a difficult yet important determination, as this material must be compatible with the high-κ dielectric of choice. Several presentations showed indications of instability of poly-Si gate electrodes on some high-κ materials, despite thermodynamic predictions of stability.

The question-and-answer sessions following each presentation, along with the panels, allowed for extensive discussion on the most important concerns for these high-κ materials. This workshop stimulated ideas and raised key questions, but the clearest point is that these issues must be resolved soon if CMOS technology is to continue on its relentless path of improved performance.



Bridget R. Rogers (left) of Vanderbilt University and Jason Kelly of North Carolina State University attended the MRS High-κ Gate Dielectric Workshop held June 1–2 in New Orleans.

Transparent Conducting Oxides: The Increasing Need of High Performance

The MRS Transparent Conducting Oxide (TCO) Workshop was held in Denver on June 19–20. Organized by David S. Ginley (National Renewable Energy Laboratory), Timothy Coutts (National Renewable Energy Laboratory),

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During the second day of the MRS Transparent Conducting Oxide Workshop, held June 19–20 in Denver, attendees participated in breakout sessions, including (a) Fundamental Studies and (b) Novel Applications. (c) The breakout groups continued their discussions over lunch on the tented patio.

Tom Mason (Northwestern University), and Clark Bright (Presstek Inc.), the workshop brought together representatives from industry, academia, and the national laboratories to discuss the state of the art for TCOs, important new technological breakthroughs, and the hurdles to be overcome for next-generation technologies. The meeting focused on large-area deposition, commercialization problems and issues, new TCO materials, fundamental TCO research, and novel applications.

More than 75 participants engaged in an interactive format consisting of key invited talks from the different sectors followed by breakout panels in the focused areas. A key element to the workshop was an effort to bring together representatives of the glass, display, electrochromic, and photovoltaic communities to talk about future needs, critical factors, and opportunities. As flat-panel displays and flat-screen TVs increase in area and demand (the market is estimated to grow to more than $85 billion by 2005), as thin-film photovoltaics drive toward gigawatt annual production levels, and as low-emissivity and smart windows become more standard, the needs for high-performance TCOs will dramatically increase.

One of the key observations from the meeting was that while TCOs are not the critical limiting factor at the present time for any of these applications, they soon will be. This is because as the respective industries continue to grow and move to larger-area devices, current TCOs will not meet performance and cost needs. One of the critical issues is that indium tin oxide is the main transparent conducting material employed in all of these applications except low-e windows (which use tin oxide). As the demand for TCO-coated materials rapidly increases, the supply of In, a relatively rare and expensive material, may become critically depleted. If this happens, new materials with comparable performance but lower cost will need to be found. This represents a major challenge to the community.

Another key area discussed was the initial development of *p*-type transparent conductors by a number of groups. Although the early work has been spearheaded in Japan, especially by the groups of Kawazoe (Hoya Corp.) and Katayama-Yoshida (Osaka University), many groups in the United States have also become active in this area. The development of *p*-type materials resides in two discrete areas: new *p*-type oxides such as $CuAlO_2$ and the nitrogen-doping or co-doping of ZnO. Current materials do not yet match the performance of their *n*-type counterparts. The potential impact, if high performance *p*-type materials can be prepared, is large, directly affecting such current applications as thin-film photovoltaics and enabling a whole new class of all-oxide electronics with unique optoelectronic properties.

Although TCOs have been commercially important for decades, rapid progress in the understanding and development of new transparent conducting materials has seen a large influx of activity over the last three years. There is a demand for extraordinary film properties coupled with high growth rates and low deposition temperatures, especially as polymer substrates gain increasing importance. The defined target figures for the electrical and optical properties that are going to be needed for next-generation devices were addressed. To support reaching these goals, a number of important research and development areas were identified during the course of the meeting. Some of these include the development of new chemical vapor deposition precursors for TCOs pioneered at Northwestern University, the development of new analytical techniques by the Colorado School of Mines and NREL, a worldwide exploration of ternary TCOs (containing Zn, Ga, and Cd), and the demonstration of very high performance indium tin oxide in both amorphous (low-temperature deposition) and crystalline forms.

Overall, the workshop provided an important integration of the various TCO communities, leading to a number of new collaborations. A key observation was the need for an increased integration of the glass industry into the TCO community. MRS

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