1988 Tungsten Workshop Attracts International Audience

The Fifth Workshop on Tungsten and Other Refractory Metals for VLSI Applications, held October 2-4, 1988, Albuquerque, New Mexico, attracted major representation from 67 U.S. companies and universities (including SEMATECH, AT&T Bell Laboratories, IBM, GE Research Laboratories, Signetics, Harris Semiconductor, Texas Instruments, Intel, Motorola, and Stanford University) as well as from various laboratories in Japan, Sweden, Germany, Holland, France, Italy, Canada, and China.

Interest in tungsten is now strong throughout the semiconductor manufacturing industry—most IC companies have formed research teams to study the metal. Almost 80% of the papers in the metallization sessions of recent major national conferences have been devoted to the new technology, compared to about 10% in 1984, when the first workshop was held. Over the last five years, the workshop series has served as a forum for advancing understanding of tungsten technology.

Increased interest in the conference has been fueled by the growing recognition throughout the semiconductor industry that a new method for depositing metal plugs is necessary to achieve the needed planarization above contact windows and to selectively fill via holes that interconnect the different metallization levels of advanced integrated circuits (ICs). Until now, aluminum or polysilicon has been used in manufacturing ICs to form the fine conductive lines that carry electrical signals from point to point. But with the drive toward greater miniaturization—and with microcircuit dimensions shrinking to the submicron range—tungsten has become one of the leading candidates for meeting the more stringent requirements for interconnect metallization.

At this year's conference, seven research groups presented papers on using silane compounds (rather than hydrogen) to chemically reduce the tungsten fluoride feed gas. The strong interest in the use of silane was fired by a surprise announcement at last year's workshop at IBM, Yorktown Heights. At that workshop, Y. Kusumoto (Ulvac Japan, Ltd.) described a new chemistry for CVD tungsten involving the use of silane. An important feature of the process is that the resulting byproduct gas is innocuous, eliminating the undesirable effects on the silicon wafers that are possible when hydrogen is used. It also increases the rate of tungsten deposition—up to 10 times faster (about one micron per minute) even at relatively low deposition temperatures (200 to 300°C), while maintaining good selectivity. This development represents significant improvement, opening the way to much higher wafer throughput, a necessary step to meet the requirements for manufacturability.

Keynote papers in this year's workshop were presented by representatives from Mitsubishi and SEMATECH: Tadashi Nishimura reviewed Mitsubishi's work toward three-dimensional ICs in which tungsten or tungsten silicide plays a crucial role to achieve workable refractory vertical wiring. James Stimmell reported on SEMATECH's decision to use CVD tungsten for contact and via fills, and stressed the growing acceptance of "Tungsten-As-Metal-One," or WAMO—the use of tungsten as the first-level wiring material. A panel discussion—"Enhancing Manufacturabililty: Opportunities and Concerns"—reflected the overall focus of the workshop.

The workshop was hosted by Sandia National Laboratories and the University of California, Berkeley. Hardbound proceedings of the workshop are now available through the Materials Research Society. Prices: $39 for MRS members, $45 for U.S. nonmembers, and $54 for foreign nonmembers. Order from the Publications Department, Materials Research Society, 9800 McKnight Road, Suite 327, Pittsburgh, PA 15237; telephone (412) 367-3012 or fax (412) 367-4373.

The 1989 Workshop on Tungsten will be held in two parts, several weeks apart. Part I will be held in the Bay Area of northern California in the early fall. Part II will follow on October 19-20, 1989 in Japan, where there is strong interest in refractory metals use in advanced ICs. This part will be hosted by the Tokyo Institute of Technology and chaired by Prof. Furukawa. Interested parties are encouraged to contribute to either or both parts. For information contact: Linda Reid, University Extension, University of California, 2223 Fulton Street, Berkeley, CA; telephone (415) 642-4151. □

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Edited by Robert S. Blewer and Carol M. McConica

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San Francisco Bay Area Hosts High T_c Triad

In January this year the San Francisco Bay area was host to three separate events featuring high temperature superconductivity:

- SC Global 89, an international superconductor applications convention sponsored by the Superconductor Applications Association of El Toro, California;
- A Superconductivity session at the joint meeting of the American Association for the Advancement of Science and the American Physical Society; and
- The seventh in a series of U.S. Department of Energy information exchanges on high temperature superconductivity.

The exchange of ideas, results, and theories on superconductivity continued at a thought-provoking, sometimes controversial pace. Topics spanned Simon Foner's emphasis on the need for realism and more knowledge, Koichi Kitazawa's explanation of why corporations are participating in ISTEC, and Leo Falicov's categorization of superconductivity theories. Current theories were brought into question by the announcement of a new n-type material discovered in Japan and by experiments which prompted national laboratory researchers to claim metallic behavior in the cuprate superconductors.

SC Global 89 Covers Applications, N-Type Superconductors, ISTEC

Over 600 people attended "SC Global 89," the second annual international superconductor applications convention sponsored by the Superconductor Applications Association of El Toro, California. Held in San Francisco, January 11-13, the convention featured nearly 100 speakers and over 30 exhibitors. Attendees could choose from four concurrent sessions: Applications and Manufacturing; University and Industrial R&D; Government R&D; and Markets, Venture Capital, and other issues.

The convention was opened by keynote speaker Simon Foner, chief scientist of the Francis Bitter National Magnet Laboratory. Foner's presentation—"The New Age of Superconducting Applications: Has it Arrived?"—emphasized the need for realism and increased knowledge.

Even though the breakthroughs in finding higher temperature materials have been a boon to all of superconductivity research, said Foner, media hype has mislead the public and would-be investors. He attributed this (tongue-in-cheek) to the elements "euphorium, fundium,* hypium, unknownium, utopium, etc." He also decried the tendencies to release research in the "minimum publishable unit," to create new topical journals (11 to date!), and to "distort science priorities." Foner emphasized that the development of the high T_c field will be, and should be, incremental over a long time and the result of arduous work.

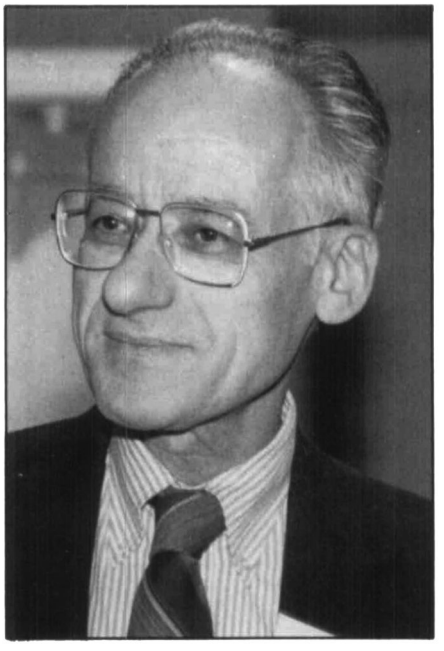
Sheridan Tatsuno of Dun & Bradstreet's Dataquest portrayed a novel scenario, recommending that applications research focus on small, low-priced items that could have volume sales. As an example, he cited William Little's microminiature refrigerator that can increase the capability of the common personal computer. While Foner described the "realistic" lack of consumer markets for superconductor products, Tatsuno encouraged researchers to be creative and to look not at the obvious possibilities, but at the hidden ones.

Several essential steps in the commercialization process have little to do with breakthroughs in basic research, said Tatsuno, and laboratory scientists tend to have little exposure to them. Tatsuno enumerated the steps needed to evaluate the efficacy and profitability of a product:

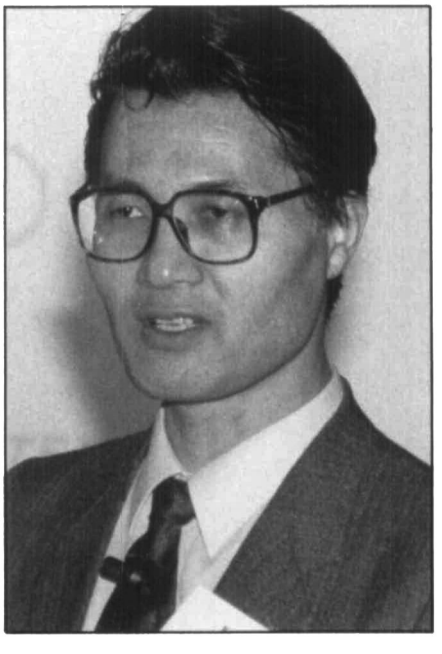
- Identify and compare the features of the emerging technology with those forecast to compete with it (e.g., don't develop the magnetic bubble memory without seeing the CMOS technology on the horizon);
- Assess and project the market for the products;
- Assess the impact of external factors such as regulatory actions, intellectual property, trade policies, the state of the economy, venture capital trends, etc; and
- Do a "land-mine analysis" to identify those events that could reduce the product to a laboratory curiosity.

Addressing an overflow lunch crowd, Koichi Kitazawa of the University of Tokyo, announced the discovery of an n-type superconductor composed of neodymium, cerium, copper, and oxygen, which superconducts at 24 K. All previously discovered superconducting cuprates have been p-type, implying that the superconductivity occurs through holes in the oxygen band or the lower Hubbard band. The discovery of an n-type superconductor implies that electrons in higher partly filled bands may also superconduct. This is a new and se-

*Another "Fonerism" worth repeating is that "...government funding is sophisticated welfare, but it is welfare well spent."



Simon Foner leads off SC Global 89 meeting with a frank assessment of the status of high T_c superconductor research and potential for applications.



Koichi Kitazawa (SC Global) describes recent high T_c developments in Japan and the rationale for corporate membership in ISTEC.

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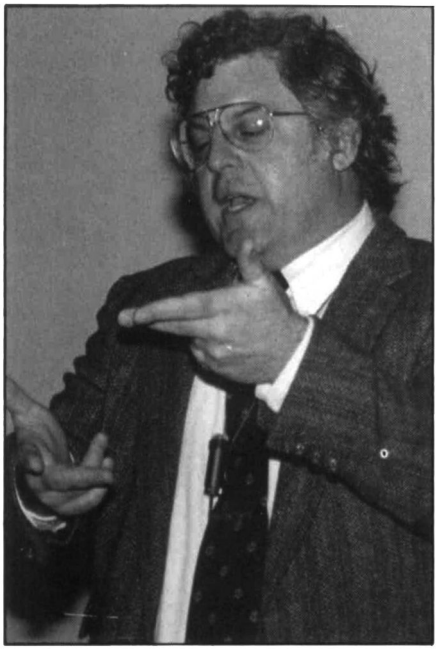
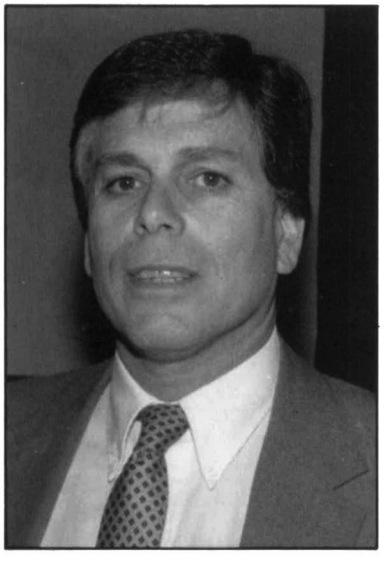


Robert Laughlin (AAAS/APS Meeting) explains how the fractional quantum Hall Effect formalism can be applied to the high-T_c phenomena.



Frank Fradin opens theory session at the seventh DOE High T_c Information Meeting.

vere test for theories, many of which have relied on valence-band holes to explain high T_c phenomena.

Kitazawa also took the opportunity to forthrightly state the reasons he believes major donor/member corporations participate in the new ISTEC consortium:

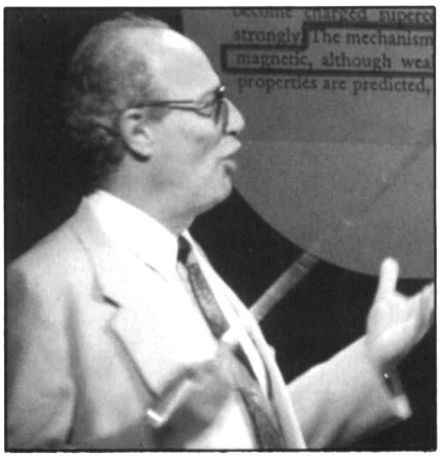
1. A publicly visible donation to scientific activities in order to keep pace with similar public-spirited actions by other companies;
2. Publicity for use as a recruiting tool;
3. Encouragement for the company's R&D group;
4. Insurance or investment (for the future);
5. Facilitating creation of a "friendly" network of communication among companies;
6. Education and training of young capable people;
7. Appearing supportive of R&D in the eyes of the government with which the company has other relations where this image may be valuable;
8. Adhering to a postwar ethic that companies have the social responsibility to invest in basic science and technology to pave the way for the future of the *whole world*.

Regarding the last motive, Kitazawa noted that the 45 or so members of ISTEC need support from abroad and an indication that such a change in attitude in Japan is welcome.

In other talks:

- Zhongxian Zhao of the Chinese Academy of Sciences Institute of Physics, Beijing, promoted a formula to predict a material's critical temperature based on his observation that internal friction peaks appear 20 K above T_c.
- Yuri Ossipyan, USSR Academy of Science, reported on the effectiveness of a chlorination rather than oxidation step to make 1-2-3 material superconducting. Ossipyan was unable to explain the precise role played by the halogen.
- Paul Chu of the University of Houston gave an after dinner presentation on the space applications for superconductivity and described the advantages of processing in space.
- Brian Ahern of the Rome Air Development Center, described his work on borides of titanium but failed to confirm the rampant rumors of room-temperature superconductivity in titanium-boride systems which had been circulating since mid-December.

Extended abstracts of the presentations at SC Global 89 will be available in May from the Superconductor Applications Association, 24781 Camino Villa Ave., El Toro, CA, 92630; telephone (800) 854-8263 or (714) 586-8727 (in California),



Leo Falicov categorizes superconductivity theories for DOE meeting participants.

The third annual international superconductor applications convention, "SC Global 90," is scheduled for January 17-19, 1990 on the Queen Mary, Long Beach, California.

AAAS/APS Meeting Reviews the State of the Field

On January 19, 1989 during the joint meeting of the American Association for the Advancement of Science (AAAS) and American Physical Society (APS) in San Francisco, Prof. Ted Geballe (Stanford University) chaired a session on high T_c superconductivity. The session primarily reviewed the state of the field. In addition to Geballe, speakers were Arthur Sleight of Du Pont and Robert Laughlin of Stanford University. (Although scheduled, Paul Chu of the University of Houston was unable to attend.)

Sleight emphasized the new n-type Nd-Ce-Cu-O 24 K material discovered in Japan as a test of theory, because of the carrier type and also because the reported structure lacks the pyramidal (apical) oxygens above *and* below copper-oxide planes present in all other cuprate materials discovered so far.

Laughlin presented a new view of a possible theoretical description of the high T_c materials. Based on the common descriptions of these materials as Mott insulators in terms of a Hubbard model, he showed how an approach which parallels the formalism applicable to the fractional quantum Hall effect, albeit with differently defined quasiparticles and statistics, can

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produce the bosons needed for the superconducting state, use the known magnetic properties of the new materials, and be essentially consistent with Anderson's resonating valence bond picture as well.

DOE Information Meeting Considers Theories

On January 27, the seventh in a series of U.S. Department of Energy information meetings on high T_c superconductivity was held at Lawrence Berkeley Laboratory. The meetings are sponsored by the DOE Division of Materials Sciences, Office of Basic Energy Sciences. As for the fifth and sixth meetings, a major portion was televised through the satellite network of the National Technological University. In addition the entire meeting was videotaped.

The first session, on theory, was chaired by Frank Y. Fradin of Argonne National Laboratory. David Emin (Sandia National Laboratories, Albuquerque) demonstrated that conditions may exist in these new materials that would favor the existence of large mobile bipolarons which would be present above T_c and be the bosons that condense at T_c. Richard Klemm (Ames Laboratory) described a phenomenological model based on the notion of quasi-hole pairs and carrier tunneling between lattice planes. Marvin Cohen and Leo Falicov (University of California, Berkeley) summarized the current state of theory and, in particular, explained why they believed a recently published magnon-exchange model was in error.

Falicov helped place the types of theories in perspective by offering a four-part categorization in terms of departure from traditional BCS theory:

1. Stretch the validity of BCS and keep the phonon-mediated interaction;
2. Use BCS but replace phonons (with excitons, etc.);
3. Give up electrons in favor of magnetic entities, RVB states, spin-bags, etc.;
4. Give up BCS and allow pairs to exist above T_c as with bipolarons.

There was agreement at this meeting as well that the new Nd-Ce-Cu-O n-type material will test many suggested theories.**

Successive panels considered New Materials and Their Properties, Electronic Structure, and Thin Films and Devices. Two developments can be mentioned. David Marshall (Rockwell) described a new measurement method using a load cell attached to a levitating magnet which determines force hysterisis and remnant fields. He thereby explained the suspension phenomenon which is especially strong in the thallium-based compounds.

The question of whether the new cuprate superconductors are metals in the usual sense (i.e., having a Fermi surface where electrons actually reside in a conduction band) generated contrasting views. Two types of experiments were discussed. R. Scott List (Los Alamos National Laboratory) interpreted photoemission studies as revealing an occupied Fermi level. (A press release from Sandia/Albuquerque the following day declared that metallic behavior was confirmed in the 1-2-3 materials by studying photoemissions from surfaces freshly cleaved at 20 K). Lars Smedskjaer of Argonne National Laboratory also claimed to see an occupied Fermi level using a positron annihilation technique.

On the other side of the issue was the proposition, as gleaned from audience comments, that seeing an edge in a photoemission spectrum does not confirm it as the top of a conduction band. Also, Richard Howell's presentation of positron annihilation results from Lawrence Livermore National Laboratory saw no evidence of a Fermi surface even though the statistical accuracy of their data was substantially higher than that of Argonne's Smedskjaer.

E.N. Kaufmann

**Pertinent to the theoretical situation, Simon Foner was heard to say at the SC Global meeting that "there are more theories than there are theorists today—that's a problem—but theories eventually converge on experimental results."

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