What is a Supermaterial?
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On rare occasions, the coining of a new term brings new ideas to a field by virtue of a shift in viewpoint. A recent example is "complexity," which collected together, from a core of deep results in mathematics and hydrodynamics, a clan of fields whose kinship had been revealed by the new term itself. More often such appellations merely follow fashionable trends. So it took courage on the part of the founders of SUPERMAT to promote their vision. Marcel Ausloos (Université de Liège, Belgium) and Gilbert Vacquier (Université de Marseille, France) have shown us a way to resonate as a new chord in materials science. As the first conference on "supermaterials," SUPERMAT and its companion SMART 99 have begun to reveal new branches of research from the established pathways explored in superconductivity.

At the conclusion of SUPERMAT in Giens, France, we participants were as energized by the exciting science that had been covered during the week as we were impressed by the French food, wine, scenery and hospitality. If the definition of a supermaterial is not obvious now—after the conference—it was certainly not obvious before it. Nevertheless, the conferees were drawn inexorably together by the conference theme. Perhaps it is not appropriate to try to understand this self organization, which surely is even more complex than the self organization of electrons in a high temperature superconductor, the theory for which still eludes us after 13 years!

A clue to the working definition of a supermaterial can be derived empirically from the topics we discussed at SUPERMAT and SMART 99. In addition to superconductors, we heard about magnetic effects of many kinds, including "giant" and even "colossal" ones that presumably trump "super" ones, organic conductors, photoconductors, and even four-hundred-year-old Japanese ceramics. A useful way to look at these topics is through the materials science tetrahedron. We see that processing is a prominent pursuit in
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supermaterials especially for, but not limited to, the superconductor subset. Characterization and theory
talks broke new ground in pursuit of useful optoelectronic phenomena. In synthesis, the parade of new
materials combinations, often in groups of four elements or more, was a continuing source of surprise. But
a clearly distinctive aspect of the conference that would not have been possible until recently is the wealth
of applications reported.

From circuits to sensors, supermaterials are making an impact on society. David Dew-Hughes (Oxford)
amazed us with a discussion of new induction motors based on superconducting, hollow cylinders that self-
center in a stator field. With appropriate vanes, the motors become compact pumps, promising for
cryofluids and microfluidic devices. Other microdevices were presented by Jean-Claude Villagier
(Grenoble) and Alain Kreisler (SUPELEC, Gif sur Yvette), who discussed remarkable superconducting
field effect transistors, bolometers, and IR detectors based on supermaterials. Paul Seidel (Jena) made clear
the path for supermaterials to impact medical technology, Enrico Silva discussed microwave devices, and
many others discussed energy applications from fuel cells to current limiter components. Finally, in a
discussion that focussed keenly on one of the limiting factors of Moore’s law, Michel Houssa (IMEC,
Leuven) presented research into alternative gate materials for microcircuits. Currently, silicon oxide gates
are approaching a few nanometers (!) and will clearly fail to meet reliability requirements. Alternative
oxides and nitrides with the required high dielectric constants were eloquently described by Ivan Nedkov,
and Placenik exhibited the excitement about artificial tunnel junction barriers.

A tour de force of high resolution microscopy and theoretical analysis was shown by David Welch
(Brookhaven) in his discussion of the importance of twinning in superconductors. The fundamental
understanding of these microstructural aspects of supermaterials may soon fall to the elegant computational
techniques covered by Georg Schmitz (ACCESS, Aachen) and Veena Tikare (Sandia), who showed how
the phase-field method can now simulate complex coupled fields leading to dendritic growth. Elzbieta
Zipper (Katowice) introduced a simple model for cooperative phenomena in magnetic materials based on
stacked rings that was of relevance to the work on manganites by Bogdan Dabrowski (DeKalb), while
Goodenough (Austin) and Manneval (Marseilles) added insights on transport cooperativity.

For electronically active supermaterials, magnetic field studies (Li, Penn State, and Damay, Imperial
College) continue to dominate characterization activities, in combination with high pressure
(Toulemonde, Grenoble), but the probing of electronic states by Ernst Kurmaev (Yekaterinburg) using x-ray spectroscopy
and that of phonon confinement by Robbes are equally fundamental. Other photonic interactions were
shown in the surprising phenomenon of persistent photoconductivity, another super property, in the
research by Alain Gilabert (Nice), and subpicosecond devices investigated by Roman Sobolewski
(Rochester). Davor Pavuna (Lausanne) explained how one engineers the bandgap of materials to achieve
such responses then reported immediately back to his lab, as he told me, the recent results on pulsed laser
deposition reported by Dave Blank (Twente).

Processing to tailor microstructure is a cross-cutting theme for supermaterials. Xerman de la Fuente
(Zaragoza, Spain) showed an exotic laser processing technique akin to zone melting, while Rudi Cloots
(Liege) suggested several outside-the-box techniques to bring greater order to superconducting grains,
otably a method inspired by closed-cell foams. At MIT, Paulo Ferreira studies magnetic field alignment
of superconductor grains in molten matrix, and in a poster discussed the exciting field of magnetically
activated shape-memory alloys for unintrusive in vivo actuators. In Japan, Takada (Okayama) is using
electrochemistry to enhance superconductors. Pavel Diko (Kosice), Genda Gu (Sydney), and Andrzej
Majchrowski (Warsaw) showed thought-provoking results drawn from the crystal growth observations and
technology, while David Caplin (Imperial College) introduced us to the mysterious angular dependence of
radiation treatments of superconductor tapes. Anna Tempieri (Italy) has made surprising progress in high
pressure synthesis of supermaterials, as has Kletkowski in the purely magnetic domain. Schmitz made a
surprise announcement of a breakthrough in HiTc processing at ACCESS, namely the use of a fabric-like
mask through which cuprate material can be microstructurally patterned to pin flux.

Finally, synthetic routes to obtain superproperties challenge chemists from both inorganic and organic
sides of the discipline. Yung Woo Park (Seoul) has identified the essential junction between polycrystalline
fibers that determines its properties as an organic conductor. Certainly polycrystalline is a supermaterial
since the fact that it conducts at all is surprising. Ionic conductors (Molenda and Vannier) offer superproperties to many applied fields. Phillipe Odier (Grenoble) introduced us to the biochemistry trick of gel-phase processing of superconductors as a way to control kinetics of reaction. This borrowing ideas across disciplinary boundaries is the essence of the materials research discipline.

In final remarks, Vladimir Kresin (Lawrence Berkeley) pointed out the continuing lack of a comprehensive theory of high temperature superconductivity as the outstanding question (still) after 13 years of HiTc. He noted with irony the re-emergence of mercury as an element of interest in the superconductor family, now numbering thousands (Hg was the first superconductor discovered). One continues to ask, how is it that carriers or other agents in a material conspire to give surprising, “super” properties? By broadening discussion to the category of supermaterials, as SUPERMAT and SMART have done, we have gained new paradigms to study this question.

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