Letters to the Editor

Monocrystals Offer Best Route to Ultrahigh-Strength Materials

To the Editor:

Some months ago, an issue of *MRS Bulletin* [vol. 28, September 2003] was devoted to high-temperature materials for aircraft gas turbines. In it, various materials types were discussed, but an important one was omitted. My purpose here is to correct this omission.

Long ago, I discussed "Ultrahigh Strength Materials of the Future."[1] I argued that the best route to new high-strength materials would be monocrystals as structural elements. The rationale was that grain boundaries and other incoherent interfaces are inherently weak, so they need to be eliminated to obtain the very highest strength. Some important validations of this principle have occurred. One is the use of diamonds as cells to obtain ultrahigh pressures.

Another validation was the invention of monocrystalline turbine blades for jet aircraft engines by Frank VerSnyder and his colleagues.[2] These are critical for constructing efficient modern aircraft. They allow higher engine operating temperatures and lower maintenance costs. VerSnyder's invention was a landmark in materials technology.

In the meantime, other proposals for improving strength have appeared. One was to search for ductile ceramics. However, an adequately ductile ceramic has not yet been found. Another proposal was to develop composites that can resist stress and temperature. Despite large investments of effort and money, the performance of such composites has been mediocre. Composites lack intrinsic shear strength, tend to be brittle, and are often chemically unstable in service. Those pesky incoherent interfaces have spoiled the proponents' dreams. The interfaces tend to be especially weak at high temperatures.

The case for monocrystals needs to be revisited. It is the only case that might successfully produce a substantial advance in high-temperature strength. However, since oxidation resistance is essential, oxide crystals, rather than metal ones, need be considered. The potentially large improvement in engine performance and operating costs will offset the large development costs.

VerSnyder's invention brought metallic alloys to the end of the line, not because of strength limitations, but because of chemical reactivity. Metals simply oxidize too easily, and their oxides are often volatile. However, some oxides themselves, particularly garnets, are chemically stable at high temperatures.

Oxide coatings are commonly put onto the surfaces of metals to protect them. But, despite substantial effort, success in real engines has been limited.[3]

The oxides with the best combination of properties are garnets. In addition to being chemically stable, they are very resistant to plastic flow. Therefore, in air, they have the best combination of stability and high-temperature strength known. Perhaps the best of them is yttrium aluminum garnet (YAG), which is an outstanding host for solid-state lasers.

At room temperature, chemically polished YAG crystals are very strong. Their fracture strengths equal 700,000 psi (5 GPa) or more. At high temperatures, their strengths are superior to other oxides and the best metal compound (nickel aluminide), as Figure 1 illustrates. At 800°C, YAG is 8.6× harder than the best ductile intermetallic compound. The creep rates for YAG crystals are low, even at 1800°C.[4]

On the downside, oxides are brittle at low temperatures. Grain boundaries in them tend to be weak at high temperatures. The use of oxide monocrystals solves the second of these problems, leaving the brittleness as a problem to be solved.

Brittleness can be circumvented by prestressing the surfaces of structural components. This is a familiar technique. Ordinary Corelle tableware obtains its exceptional durability in this way. Corelle plates can be dropped from heights of several feet onto hard surfaces without breaking. An ion-exchange process has been used to expand their surface layers, thereby pre-compressing them and inhibiting crack formation.

The feasibility of applying this approach to high-temperature materials has been demonstrated by Marion, Gualtieri, and Morris[5] with considerable success. They precipitated a thin epitaxial layer of YAG containing holmium (Ho) onto the surfaces of pure YAG crystals. The holmium increased the specific volume of this layer, compared with that of the underlying YAG, so the layer was put into compression. As a result, it increased the strength by 6× and more. Since the layer is epitaxial, it does not relax at high temperatures.

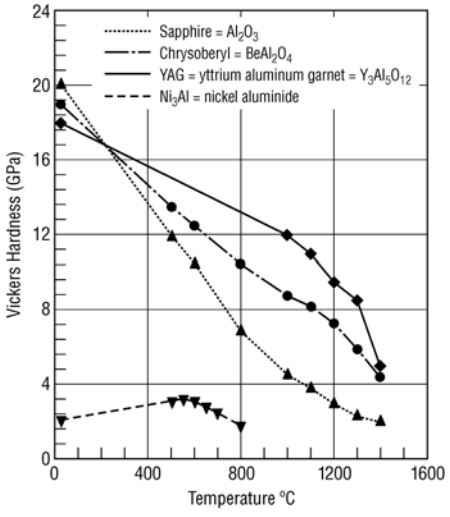

Figure 1.

The path to practical materials of the pre-stressed type will be very demanding. However, Morris and his colleagues have demonstrated the feasibilities of the various steps along the way.

The reward for solving the several problems presented by this technology is markedly improved engine operating efficiency. Increased reliability might also be achieved. These factors would offset the increased manufacturing costs.

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References

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5. J.E. Marion, D.M. Gualtieri, and R.C. Morris, "Compressive Epitactic Layers on Single-Crystal Components for Improved Mechanical Durability and Strength," *J. Appl. Phys.* **62** (1987) p. 2065.

Response:

Oxide-based materials were downplayed in our issue because of the inherent limitation of poor impact strength, despite the attractions of good chemical stability and good high-temperature strength, as shown by the examples in Figures 2 and 3, respectively, from our Introduction [pp. 624–625]. Dr. Gilman is to be commended for re-emphasizing the benefits of monocrystals and especially for calling attention to the possibility of circumventing the brittleness problem in oxides by chemically pre-stressing the surface layer of the crystal. It remains unclear, however, why this approach has not been more vigorously pursued since its first demonstration of feasibility on YAG almost 20 years ago by Marion, Gualtieri, and Morris [Ref. 5 in Dr. Gilman's letter]. We note, however, that Morris et al. obtained a patent on a single-crystal oxide turbine blade in

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1998 (U.S. Patent 5,756,225).

We cannot agree with Dr. Gilman's statement, "…. despite substantial effort [on oxide coatings], success in real engines has been limited." Thermal barrier coatings (TBCs), such as the Y_2O_3-stabilized zirconia (YSZ), described by Padture, Gell, and Jordan [Ref. 3 in Dr. Gilman's letter], are widely used nowadays in both jet engines and land-based gas turbines. The application of the TBC increases the temperature capability and life of the airfoil at least as much as the introduction of single crystals.

J.-C. Zhao, GE Global Research
J.H. Westbrook, Brookline Technologies
Guest Editors for *MRS Bulletin* **28** (September 2003)

Open Access to Online Journals Critical for Scientific Advancement

To the Editor:

In June 2003, publishing companies began prohibiting public access to the scientific literature at publicly funded university libraries for the first time in history. Although online publishing promises a great benefit to the scientific and engineering communities by allowing convenient literature searching and more efficient, cost-effective publishing, not everyone is benefiting. Many professional scientists, medical doctors, engineers, and the general public who previously had free access to printed journals at these libraries have been banned from the literature, as many libraries have been forced by publishers to discontinue printed journals and restrict their online journal access to faculty, staff, and students only. Access to online journals by any other means is prohibitively expensive.

This is a problem that bothers me both philosophically and personally.

First and foremost, taxpayers fund most of the research published in the scientific literature and should therefore have access to it at publicly funded university libraries. The need for inexpensive access to the literature is vital for the public in many ways and has several effects on the scientific, engineering, and medical communities as well.

The current prohibition effectively bans almost anyone not associated with a university from applying for tenure-track university positions. Developing the necessary research proposals for applying is difficult to nearly impossible without access to the literature. Although many workers in industry have access to the literature through their employers, they can only use this access for business purposes.

Outsourcing of U.S. jobs requires that U.S. workers re-train to transition into new jobs. Unemployed scientists and engineers find it difficult to keep up with their fields or learn about new areas without access to the scientific and engineering literature.

Female scientists and engineers, such as my wife, who take time off work to have and raise children cannot effectively keep up with progress in their disciplines without access to the literature. They are limited to internet searches and journals like *Science* and *Nature*, which are available in most public libraries. These journals and the Internet allow one to scratch the surface, but they do not allow for in-depth study. My wife is a molecular biologist, and her discipline is rapidly progressing. Her knowledge will be outdated when she is able to go back to work.

Citizens who need to make informed decisions regarding medical care cannot directly research reports in medical journals because of this prohibition. In fact, private medical doctors sometimes find it difficult to access the medical literature.

Finally, I do not believe that publishing companies should profit by exploiting taxpayer-funded research, relying on professionals to review papers for free, and straining library budgets by increasing journal prices at a rate much higher than inflation. There is little or no competition to keep journal prices in check.

It is beyond the scope of the Materials Research Society (MRS) alone to solve this problem because it will require a broad national or even international consensus. Ideally, the scientific literature should be free for all. This is a long-term problem in which the legitimate costs of publishing must be considered. In my opinion, walk-in library access to the literature is the short-term solution that affects most private individuals.

I would like to see MRS take a position regarding public access in at least three ways. First, set an example of fiscally responsible access to MRS online journals and ensure that libraries may allow walk-in access to online MRS journals to which they subscribe. Second, formulate and advocate an open-access policy position toward the scientific community and government funding agencies. Third, encourage other professional societies, such as the American Chemical Society, to allow walk-in access to their journals and coordinate joint advocacy efforts.

E. Todd Ryan
Advanced Micro Devices

Response:

Todd Ryan argues eloquently from personal experience as well as moral conviction for open access to the scholarly research literature. I am responding to Todd's letter because issues related to the scope of MRS publications as well as access to those publications are part of the purview of the MRS Information Services Committee of which I am the current chair. I note, however, that my response has benefited from input from MRS headquarters staff and other MRS members.

This response to Todd's letter is in four parts: (1) discussion of the basics of open-access or open-archive initiatives as I understand them, as well as the fiscal realities of publishing; (2) a response to his request that MRS "…set an example of fiscally responsible access to MRS online journals…."; (3) a response to his suggestion that MRS "…ensure that libraries may allow walk-in access to online MRS journals to which they subscribe"; (4) discussion of ongoing activities within MRS to "…formulate and advocate an open-access policy position toward the scientific community and government funding agencies" as well as coordination of efforts with other societies.

Movements for open access to the scholarly research literature, including the Public Library of Science, are currently generating significant debate within scholarly research societies; they are concerned with the financial implications of open access as well as with the moral and logistical implications. Some scholarly societies and for-profit publishers have implemented open access to some of their publications. There has been significant internal discussion within the leadership of MRS over issues related to open access almost from the inception of the current movement. The Society is receptive to the ideals of open access, so long as they can be achieved in a fiscally responsible manner. MRS follows a fiscally responsible publications strategy that already provides significant value to the members of the Society, the larger materials research community, and the public.

Regular membership in MRS costs $100/year. Retired/student/unemployed memberships are available for $25/year. Both forms of membership include access to the full text of much MRS content. These low rates (even for regular membership) provide real value for the money. Thus, a student who graduates and has not yet found a job, or a person who loses his or her job, can have online access to everything MRS publishes, except for the full-text articles of the *Journal of Materials Research*, for $25/year. Furthermore, a tremendous amount of materials-related content is available on the MRS Web site (www.mrs.org) free of charge, not only to

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members, but also to the general public with access to the Internet.

Open Access and Fiscal Responsibility. Hopefully, the distinction is clear between "open access," "online access," and "free access." Most publishers today offer some online access to their journals, conference proceedings, and other information through member and nonmember (including library) subscriptions. Some publishers offer open access to some scholarly literature in that the information is available online and free to readers. To the best of my knowledge, there is no journal or other source of scholarly information for which there is completely "free access." Every form of publication has costs that must be paid by someone, whether by readers, authors, sponsors, the government, or a combination. By that definition, "free access" is impossible.

Consequently, financial models for access to scholarly literature include (1) reader-pays, (2) author-pays, (3) sponsor-pays, (4) government-pays, and (5) combinations. All of these approaches have advantages and disadvantages, producing both advocates and opponents. Traditional sources of scholarly literature (e.g., scholarly societies and for-profit publishing houses) have followed some form of model 5, extracting page charges from authors when practical and relying on subscriptions from individuals and libraries, as well as sponsors. In this approach, libraries have usually borne the heaviest financial burden. I note here that publishers using this model are seeing declining revenue because of declining library subscriptions to most publications. The sources of this decline are complex, and I cannot discuss them here because of space limitations.

I believe that the original architects of "open-access" initiatives such as the Public Library of Science envisioned a limited form of "free access," that is, free to both authors and readers. Although their current financial model owes much to sponsors (model 3), their overall financial model has evolved to include elements of the author-pays model with limited exceptions for indigent authors. Some societies and for-profit publishers offer free access to a limited number of online publications. However, the financial models for those publications are also often author-pays models with limited exceptions for indigent authors. Although the publications of this type of which I am aware are in general well managed, the community is aware of the possibility that journals following this financial model (model 2) have some of the characteristics of a vanity press. This perception will be exacerbated if publications of this type come to value the ability to cover page charges more than they do technical content.

Approaches in which the costs are paid for by sponsors (model 3) or the government (model 4) have the potential advantage that costs are moved away from both the readers and authors, but many people who have considered these approaches worry about the propriety of having sponsors or the government determine which publishers, publications, or authors to support. In other words, will the process become hostage to political, religious, or other agendas? An example of model 3 is publications from organizations such as the Creation Research Society (TCRS). Readers should expect that papers published by TCRS espouse the organization's particular viewpoint.

An example of model 4 is an online archive such as http://arxiv.org/. Such repositories certainly follow the approach envisioned by Dr. Ryan in terms of allowing online access that is free to both authors and readers. I am aware of no efforts to limit author access to such archives, with the exception of materials that are libelous or cross other well-accepted boundaries. However, even where the archives are run as a labor of love so that there are no (or limited) staff costs, there are costs associated with maintaining the archive, such as fees for computer hardware and software. Furthermore, the papers contained within are not peer-reviewed or copy-edited. Although publications contained in the online archives are of value to specialists, it is not clear to me that the general public benefits much from open access to such literature. How can laypersons be expected to navigate the complicated web of information contained in such sources and obtain sensible, understandable, and trustworthy answers to their questions?

In every survey of the scholarly research community of which I am aware, both peer review and copy editing are highly valued. In order to issue scholarly publications that include peer review and copy editing, publishers must shoulder the costs for personnel (e.g., schedulers, copy editors, editors, production, Web markup, and linkage) as well as equipment (e.g., hardware, software, maintenance, routine upgrades, and periodic translation [migration] to new standards and technologies such as archiving data on new DVDs). Although much communication between authors, editors, and reviewers is performed electronically today, some publishers still work with hard copy delivered through the postal service. Additionally, for information delivered in print format, publishers must shoulder the costs of printing and delivery of the issues.

I believe it unlikely that we will ever see the day when a significant portion of the peer-reviewed scholarly literature is delivered in print format through open-access approaches. The costs are just too great. I believe it is much more likely that the current trend toward a gradual movement of a subset of the peer-reviewed scholarly literature into open online access in which the costs are covered through combinations of financial support from sponsors and author-pays (with limited exceptions for indigent authors) will continue. These open-access archives are also more likely to come from publishers (including societies and for-profit publishers) whose overall financial success allows such investment for the public good.

Fiscally Responsible Access to MRS Publications. MRS publishes the *Journal of Materials Research (JMR)*, the *MRS Internet Journal of Nitride Semiconductor Research (MIJ-NSR)*, the *MRS Bulletin*, and proceedings of MRS symposia. *JMR* and the *Bulletin* are accessible through print and online versions. *MIJ-NSR* is only available online. All current proceedings are accessible in online format and many are also accessible in print format. In addition, MRS maintains its Web site with a vast amount of information available online. The MRS publications enterprise currently provides the Society with revenue beyond its cost, which is used to offset the cost of other MRS activities.

Some of the literature published by MRS is available free online to the general public, but much of it is available only to members, and some of it is available only to subscribers or purchasers. The online version of *MRS Bulletin* is about 50% open to the public (the public that has access to the Web, including those who can go to a public library and access the Web). Many of the department articles are open, the introduction to the monthly technical theme is open, and abstracts to all articles are open. At the moment, the full text of the technical articles is usually open to members only and to institutions with subscriptions. Full access to all *MRS Bulletin* information is a benefit of MRS membership.

MIJ-NSR is 100% open to readers with access to the Web. It is supported 100% by page charges, sponsorships, and contributions from MRS. However, *MIJ-NSR* has not attracted a large author constituency.

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Issues of *JMR* are available online from 1996 forward with full-text articles, but require a personal subscription or access to a library subscription. Public access to the tables of contents (including title, authors, and abstracts) is available for these volumes. Full-text articles from volumes 1–10 (1986–1995) are not available online, but will be in the near future. Public access to the tables of contents for volumes 1–10 includes titles, authors, and abstracts. Personal subscriptions to *JMR* are available to MRS members within the United States for $120/year ($870/year for nonmembers, principally institutions). Subscription rates for individuals and libraries outside the United States are higher, reflecting shipping costs. Subscribers to *JMR* have access to both the print and online versions.

MRS proceedings volumes are currently published in online format, and some volumes are published in print format. No volumes prior to 1998 are currently available online, but we expect all prior volumes to be available in online format in the near future. Access to all online proceedings volumes is a benefit of membership in MRS. Public access is available for tables of contents including titles and authors, but not abstracts, for all online volumes. Print volumes are available from the Society at a nominal cost. Other forms of access, including individual article access, are available at a nominal cost.

As I indicated near the beginning of this letter, the various forms of membership in MRS are reasonable in cost and represent an exceptional value in terms of access to online publications. Full access to *JMR* is relatively inexpensive compared with similar high-quality, peer-reviewed publications on materials research from other societies and commercial publishers.

Access to MRS Publications through Libraries. In regard to access to MRS online content through libraries, I note the following. MRS's licensing agreement for IP access to its publications defines "authorized users" of an institution as "employees, staff, students officially affiliated with the institution, and persons with legal access to the institution's library collections and facilities on-site, using an IP address within the range [identified by the institution]." Such a description allows the institution to continue to serve its general patrons as they typically would with their traditional print collections. At present, IP access is a single price for any institution with online usage, and MRS only monitors general levels of usage with the intent of instituting a better pricing model in the future, based upon activity levels (not by who is accessing the information). We also look for levels of activity that are out of the ordinary that might indicate systematic downloading of documents (in such cases, we would take such concerns back to the subscribing institution for action). Our intent is not to limit service of the library to any of its patrons, but rather to limit the large-scale theft of MRS proprietary content by human action as well as automated download through Web robots. Discrimination against mass downloading of content is a policy followed by other societies, commercial publishers, and most online archives (see, e.g., the policy statement on automatic downloading on the main page at http://arxiv.org/).

MRS Position on Open-Access Policies and Coordination with Other Societies. Although open-access initiatives have been actively discussed within MRS for several years now, there is no official MRS policy or position in regard to open access. The Information Services Committee and the Board of Directors have discussed the implementation of an online materials journal similar to *MIJ-NSR*, but with a broader scope. However, no conclusion has yet been reached in regard to implementation of such a journal. Furthermore, although MRS routinely discusses publication efforts with a number of societies, there has been little activity to coordinate efforts in terms of open-access initiatives. My personal opinion on open access, which I encourage the Society to endorse, is as follows.

Materials research (as with other scholarly research) is truly a human endeavor largely (but not completely) performed for the benefit of all people and paid for largely (but not completely) by all people. In an ideal world, online access to all scholarly publications would be available free to everyone. MRS should continue to explore options for open online access of as much of its scholarly literature as possible, consistent with these general principles as well as the constraints imposed by the necessity for fiscal responsibility. MRS should also explore opportunities with other like-minded scholarly societies for joint publications consistent with these ideals.

Finally, even if MRS adopted a policy of open access for readers today, it would do most people little good in and of itself. The scholarly literature in materials research worldwide dwarfs the amount published by MRS alone. Furthermore, even if all of the scholarly societies involved in materials research approved open online access, then readers would have access to a significant fraction of the published work, but only a fraction. Access to 100% of the work published in materials research would require commercial publishers as well to agree to open access. In addition, libraries would have to maintain equipment to facilitate online access for those patrons without their own Internet access.

I would like to take this opportunity to expand our discussion to our readership. The issues related to open access are of significant importance to the Society. MRS works constantly to improve the dissemination of materials-related content to members, the larger materials research community, and those members of the general public with an interest in materials. Consequently, I would like to hear from our readers and I welcome information on successful and unsuccessful examples of open-access publications. Responses to these two letters and opinions on open access may be sent to openaccess@mrs.org. If there is enough response, I promise to revisit this discussion in a future issue of *MRS Bulletin*.

Steven C. Moss
Chair, MRS Information Services Committee
Member, *MRS Bulletin* Editorial Board

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