Physical Metallurgy: Providing Unifying Principles in Diverse Areas of Materials Engineering

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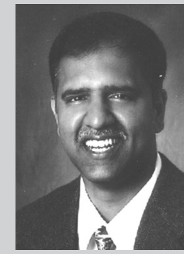

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Physical metallurgy as a subject is undergoing an evolution, perhaps a revolution. This transformation is a side effect of the field of metallurgy being subsumed into the field of materials engineering. "Materials Engineering" or "Materials Science" is now to be found in the official names of most of the former metallurgical programs. The words encompass the intersection of a large number of disciplines and subjects (e.g., biology, physics, chemistry, and mechanics). Ceramics programs also have been similarly transformed, leaving only a few dedicated "ceramic engineering" programs standing. A quick survey of the University and Academic Programs in Materials on the TMS web site (*www.tms.org/Resources/Resources2.html*) shows that less than 20% of departments have mining or metallurgical engineering in their name.

Technical societies have followed suit—willingly or otherwise. Some examples of name changes in professional societies, in response to profound shifts in member profiles, global trade, government funding trends, etc., include: TMS, which was "The Metallurgical Society" renamed as "The Minerals, Metals & Materials Society" and the Institute of Metals (United Kingdom) changing to the Institute of Materials, and now to the Institute of Materials, Minerals and Mining (IOM^3).

The traditional metallurgy curriculum has had to be revamped (perhaps more than once) to accommodate the necessity of living up to the materials theme. This means the curriculum must encompass ceramics, polymers, composites, and biomaterials, in addition to traditional metallurgy courses. The ensuing reduction in academic credit hours available for metallurgy instruction has made it virtually impossible to teach classic iron- and steel-making courses. Bessemer may well become an unknown word to future (if not current) students. In addition, there is an ongoing trend to make metallurgical topics more broad-based (e.g., discussions on creep of metals tend to include viscoelasticity—a topic that used to be more in the arena of traditional polymer science).

As educators, we are constantly faced with the question, "Why do we have to know this information?" from the students. In this new century, not too many students appear to be excited by steel refinement, nor do many find employment in metal refinement or fabrication. Instead, students are more likely to be motivated (and perk up in classes) by materials in high-profile applications, such as those in the microelectronics and biomedical industry. Are we thus faced with the demise of metallurgy as a subject or an entity?

We think not. In fact, in no way are we suggesting that the above-mentioned trends are bad. We are merely pointing out that this fusion of formerly distinct fields is cause for reflection, hopefully leading on to purposeful action, as in re-thinking the way we teach and think about metallurgy. The principles that were the bedrock of traditional metallurgical education are still highly relevant and essential to the understanding of phenomena on the atomic and microstructural level, irrespective of the class of material. The design and development of new materials often follows the approach of traditional metallurgical alloy design. Thus, rather than eliminating metallurgy from curricula, perhaps the way we teach, learn, or view metallurgy needs to be updated. In particular, in this issue of *JOM,* we would like to focus on physical metallurgy and its applicability to diverse fields.

The first article by R. Cahn has its origins in his Turnbull lecture delivered at the 2002 Materials Research Society Fall Meeting. He elegantly traces the history of physical metallurgy and brings us up to a pivotal point in time—Does metallurgy stay with materials or branch off into its own entity? Cahn presents the predicament as not necessarily a "crisis" but an "opportunity." He also provides some interesting thoughts on the current status and the future of physical metallurgy.

The impetus to eliminate lead-based solders opens up great opportunities to apply metallurgical principles to create new, lead-free solders. K. Subramanian and J. Lee present several key concepts in the next article, "Physical Metallurgy in Lead-Free Electronic Solder Development." They present many issues and challenges for materials engineers to address that necessitate a good knowledge of metallurgy. Diffusion, solidification, and intermetallic formation all play significant roles in the microstructure of electronic solders. Solder joints experience wide thermal fluctuations and stresses, and the performance of solders relies heavily on the resulting properties of the new solder materials. Creep, fatigue, and crack propagation are all topics discussed in traditional metallurgy courses but are also quite applicable in the development of solders.

While shape-memory NiTi alloys are normally the popular party trick or neat demonstration staple in many materials outreach efforts, these alloys have found a practicable niche in the medical field as biocompatible materials. The super-elastic property of NiTi is utilized in many of the stents used today. The article by A. Pelton, S. Russell, and J. DiCello from Nitinol Devices & Components nicely outlines the basic processing steps of NiTi alloys from the raw material to the final product. Vacuum-induction melting and vacuum-arc remelting are explained and the effects of impurities and cold working are addressed. Again, numerous concepts in metallurgy are required to fully appreciate the structure and properties of the material. The NiTi alloys have provided an interesting system to present and tie together several different concepts in materials engineering. The tight engineering specification on the performance of these materials requires stringent control on the alloy compositions and processing.

Solar cells are a very crucial aspect of the ongoing efforts to achieve progress in energy alternatives to fossil fuels. This is an area where the interplay of physics and metallurgy is indeed powerful. In his article, M. Mauk traces the background of photovoltaic devices and discusses silicon solar cells. After briefly describing the production of silicon, he moves on to the process engineering aspects of the purification of solar-grade silicon. He discusses solidification and crystal growth, diffusion, gettering, and metallization. He concludes with some thoughts on the future areas for exploration. It is clear from Mauk's paper that critical aspects of silicon cell manufacture benefit from the knowledge of solidification, phase diagrams, thermodynamics, and kinetics.

This set of articles, which deal with quite a diversity of materials classes and issues, have all one theme in common—the basic principles of traditional physical metallurgy are indeed adaptable to the new century's high-tech needs. Today physical metallurgy can be manifested in different forms, but the underlying principles are still the same. The challenge then is in the ability to change—to transform the traditional approach to learning—while preserving the unity of principles as applied to a diverse set of problems.

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