Preface

The demand for efficient thermal management has increased substantially over the last decade in every imaginable area, be it a formula 1 racing car suddenly braking to decelerate from 200 to 50 mph going around a sharp corner, a space shuttle entering the earth's atmosphere, or an advanced microprocessor operating at a very high speed. The temperatures at the hot junctions are extremely high and the thermal flux can reach values higher than a few hundred to a thousand watts/cm^2 in these applications. To take a specific example of the microelectronics area, the chip heat flux for CMOS microprocessors, though moderate compared to the numbers mentioned above have already reached values close to 100 W/cm^2, and are projected to increase above 200 W/cm^2 over the next few years. Although the thermal management strategies for microprocessors do involve power optimization through improved design, it is extremely difficult to eliminate "hot spots" completely. This is where high thermal conductivity materials find most of their applications, as "heat spreaders". The high thermal conductivity of these materials allows the heat to be carried away from the "hot spots" very quickly in all directions thereby "spreading" the heat. Heat spreading reduces the heat flux density, and thus makes it possible to cool systems using standard cooling solutions like finned heat sinks with forced air cooling. A quick review of the available information indicates that the microprocessors heat fluxes are quickly reaching the 100 W/cm^2 values, which makes it very difficult to use conventional air cooling (see for example, "Thermal challenges in microprocessor testing", by P. Tadayan et al. Intel Technology Journal, Q3, 2000, and Chu, R., and Joshi, Y., Eds. "NEMI Technology Roadmap, National Electronics Manufacturing Initiative", Herndon, VA, 2002).

One approach to address this problem is to design and develop materials with higher thermal conductivities. This is possible by developing a detailed understanding of the thermal conduction mechanisms in these materials and studying how the processing and resulting microstructures affect their thermal properties. These aspects are the subject matter of review in this book.

We have chosen to review our current understanding of the conduction mechanisms in the high thermal conductivity materials, various techniques to measure the thermal conductivity accurately, and the processing and thermal conduction properties of a few candidate high thermal conductivity materials. This is by no means an exhaustive review, but the chapters authored by internationally known experts should provide a good review of the status of their field and form a sound basis for further studies in these areas.

The eight chapters in this book are arranged to provide a coherent theme starting from theory to understanding of practical materials, so a scientist would be able to optimize properties of these materials using basic concepts. In Chapter 1, Srivastava covers the thermal conduction mechanisms in nonmetallic solids in some detail. The thermal conductivity expression derived is used to provide guidelines for choosing high thermal conductivity materials. Thermal conductivity results for various materials including diamond, carbon nanotubes, and various other forms of carbon are presented. The results are also extended to polycrystalline, and low dimensional systems. In Chapter 2, Morelli deals with the thermal conductivity of materials near their Debye temperatures. It also compares the results of a simple model to experimental data from various classes of crystal structures. Ashegi et al. discusses accurate characterization of thermal conductivity of various materials in Chapter 3. They review various thermal conductivity measurement techniques available to a researcher in detail, and also recommend techniques particularly suitable for high thermal conductivity materials like AlN, SiC, and diamond. In Chapter 4. Fournier reviews an elegant technique, perfected by her group, for measuring thermal conductivity on a very small spatial scale in heterogeneous materials. It is believed that this technique would be very important when evaluating thermal performance of complex systems. Virkar et al. provides the current status of the understanding of processing, and resultant thermal conductivity of aluminum nitride ceramics in Chapter 5. This chapter lays out the thermodynamic foundation for processing that will result in oxygen impurity removal from AlN, and thus increase its thermal conductivity. We hope that general application of these concepts will help researchers optimize thermal conductivity of a host of material systems. In Chapters 6 and 7, Goela et al. describe the details of CVD-SiC, and diamond materials processing and their properties. Here again the inter-relationship between the microstructure development through processing, and its effect on thermal conductivity is presented. Finally, in Chapter 8, Kwon et al. describe theoretical and experimental aspects of the thermal transport properties of carbon nanotubes. The strong carbon atom network in these novel materials lead not only to very unusual mechanical and electrical properties, but also to high thermal conductivity along the tube axis. We hope that the concepts described in these chapters will survive the test of time, and launch many curious scientists into their own forays in this field of highly interesting materials and their properties.

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