APPLICATIONS OF SONOCHEMISTRY TO MATERIALS SYNTHESIS

K.S. SUSLICK, M.M. FANG, T. HYEON, M.M. MDLELENI

Department of Chemistry
University of Illinois at Urbana-Champaign
601 S. Goodwin Ave., Urbana, IL 61801, USA

1. Introduction

One of the most important recent applications of sonochemistry has been to the synthesis and modification of inorganic materials [1-5]. In liquids irradiated with high intensity ultrasound, acoustic cavitation drives bubble collapse producing intense local heating, high pressures, and very short lifetimes; these transient, localized hot spots drive high energy chemical reactions [5-11]. As described in detail elsewhere in this monograph, these hot spots have temperatures of roughly 5000°C, pressures of about 1000 atmospheres, and heating and cooling rates above 10^10 K/s. Thus, cavitation serves as a means of concentrating the diffuse energy of sound into a unique set of conditions to produce unusual materials from dissolved (and generally volatile) solution precursors.

Ultrasonic cavitation in liquid-solid systems produces related phenomena. Cavity collapse near an extended solid surface becomes non-spherical, drives high-speed jets of liquid into the surface, and creates shockwave damage to the surface [11]. This process can produce newly exposed, highly heated surfaces and is responsible for the erosion/corrosion problems associated with hydrodynamic cavitation [12]. Furthermore, during ultrasonic irradiation of liquid-powder slurries, cavitation and the shockwaves it creates can accelerate solid particles to high velocities [13, 14]. As discussed later, the interparticle collisions that result are capable of inducing striking changes in surface morphology, composition, and reactivity [1-5, 14].

There is a wide range of chemical and physical consequences that high intensity can induce, as shown schematically in Figure 1. The chemical effects of ultrasound fall into three areas: homogeneous sonochemistry of liquids, heterogeneous sonochemistry of liquid-liquid or liquid-solid systems, and sonocatalysis (which overlaps the first two). Applications of ultrasound to materials chemistry are found in all of these areas. Chemical reactions are not generally seen in the ultrasonic irradiation of solids or solid-gas systems.

To demonstrate the utility of sonochemistry in materials synthesis, we will examine a range of applications discovered at the University of Illinois. Specifically, we will describe the sonochemical synthesis and heterogeneous catalytic studies of nanostructured amorphous iron and alloys, nanostructured Fe on silica, nanocolloids of Fe, and nanostructured Mo2C and MoS2. In addition, we will summarize earlier studies on the effects of high intensity ultrasound on slurries of inorganic solids.
2. Synthesis of Nanostructured Inorganic Materials

Solids made from nanometer sized components often exhibit properties distinct from those of the bulk, in part because clusters that small have electronic structures that have a high density of states, but not yet continuous bands [15-17]. Such nanostructured materials have been a matter of intense current interest, and several preparative methods have been developed for their synthesis. Nanostructured material syntheses include both gas phase techniques (e.g., molten metal evaporation, flash vacuum thermal and laser pyrolysis decomposition of volatile organometallics), liquid phase methods (e.g., reduction of metal halides with various strong reductants, colloid techniques with controlled nucleation), and mixed phase approaches (e.g., synthesis of conventional heterogeneous catalysts on oxide supports, metal atom vapor deposition into cryogenic liquids, explosive shock synthesis). To this range of techniques, over the past ten years we have added the sonochemical reactions of volatile organometallics as a general approach to the synthesis of nanophase materials, as shown in Figure 2.