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Review

Sonochemistry: Science and Engineering

Nimesh Pokhrel *, Phani Kiran Vabbina, Nezih Pala

Integrated Nanosystems Research Lab, Florida International University, 10555 W Flagler Street EC 3975, Miami, FL 33174, USA

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Sonochemistry offers a simple route to nanomaterial synthesis with the application of ultrasound. The tiny acoustic bubbles, produced by the propagating sound wave, enclose an incredible facility where matter interact among at energy as high as 13 eV to spark extraordinary chemical reactions. Within each period – formation, growth and collapse of bubbles, lies a coherent phase of material formation. This effective yet highly localized method has facilitated synthesis of various chemical and biological compounds featuring unique morphology and intrinsic property. The benign processing lends to synthesis without any discrimination towards a certain group of material, or the substrates where they are grown. As a result, new and improved applications have evolved to reach out various field of science and technology and helped engineer new and better devices. Along with the facile processing and notes on the essence of sonochemistry, in this comprehensive review, we discuss the individual and mutual effect of important input parameters on the nanomaterial synthesis process as a start to help understand the underlying mechanism. Secondly, an objective discussion of the diversely synthesized nanomaterial follows to divulge the easiness imparted by sonochemistry, which finally blends into the discussion of their applications and outreach.

* Corresponding author.
E-mail address: NPOKH002@FIU.EDU (N. Pokhrel).

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1. Introduction

By virtue of their unique properties that differ significantly from their bulk counterparts, nanomaterials offer novel applications to the field of science and technology. Reducing the size of a material to nanoscale confines the electrons (and photons) inside to limited movement that brings changes to its physical and chemical property [1,2]. Such expedient change have fostered many new applications while improving existing ones. Therefore, the idea to synthesize nanomaterials with desired morphology and applicable property have spurred great interest and technological evolution. From simple solution based methods like sonochemistry, solvothermal, hydrothermal etc., to cutting edge methods like lithography, epitaxy, ablation etc., the diversity in nanomaterial synthesis technique can be exploited to achieve control over growth. Sonochemistry offers a unique control over crystallinity that enables synthesis of amorphous metals and metal alloys. Compared to most methods, sonochemistry is very inexpensive and economical, allowing individual researchers and enthusiasts experience and try ideas. It rose into prominence with the rise in interest in material processing and engineering since past 30–40 years. However, study of chemical reactions and changes in chemical solution with the application of ultrasound dates back to as far as early 20th century [3]. Reports have marveled and helped the field span manifold while arousing researchers and reviewers. Review on sonochemistry, therefore, is not uncommon. However, the common discussion on types of material synthesized and their synthesis route, without focus on the effect of applied parameters on their growth and the advancements they have bought, provide more information and less insight. Our objective is to provide a comprehensive review, bringing together all necessary information to help understand the theory and methods of sonochemistry and its contribution to various fields.

Ultrasound passing through a solution creates regions inside the solution with high and low pressure region according to the periodic compression and expansion [4,5]. This change in pressure marks the inception of sonochemistry, as it precedes the crucial process of acoustic cavitation i.e. formation, growth and collapse of acoustic bubble. Air molecules dissolved in the solution diffuse to form bubbles at the low pressure cycle. On reaching the next cycle, the high external pressure compresses the bubble and the matter inside violently. This process of bubble growth and compression continues until the external pressure dominates and the bubble collapses, as shown in Fig. 1. As they contract, the acoustic bubbles, with high energy particles inside, emit light (200–800 nm) for a very brief period (about 100 ps). This phenomenon, known as sonoluminescence, can be used to analyze the condition inside the acoustic bubble [6–8]. With the help of such tools and theories, pressure and temperature inside the bubble has been calculated to rise to more than 1000 atm and 5000 K during cavitation [9,10]. The core region, known as the hotspot, feature high-energy particle collision that generate energy as high as 13 eV [11]. Extreme cases of ionization and formation of plasma inside the bubble have been reported with different chemicals and solvents [12–14]. Evidence of nuclear fusion during cavitation, though a disputed concept, epitomizes the effect of ultrasound and presents a simple, viable tool to study nuclear reactions [15]. Such conditions can induce abnormal physical and chemical changes and facilitate the very basic reaction between atoms and molecules to produce extraordinary class of materials [16–21]. However, the utility of sonochemistry lies in the fact that the ions and radicals inside the bubble comes from the chemical solution; therefore, choosing appropriate chemicals based on their vapor pressure can help customize the overall process.

In addition to the hotspot energy and associated chemical effects, the acoustic bubbles give rise to useful physical phenomenon during collapse, as shown in Fig. 2. The physical phenomenon arises either from implosion due to ambient pressure or explosion due to boundary. Bubble that reach the boundary explode outwards to produce microjets that offer distinct

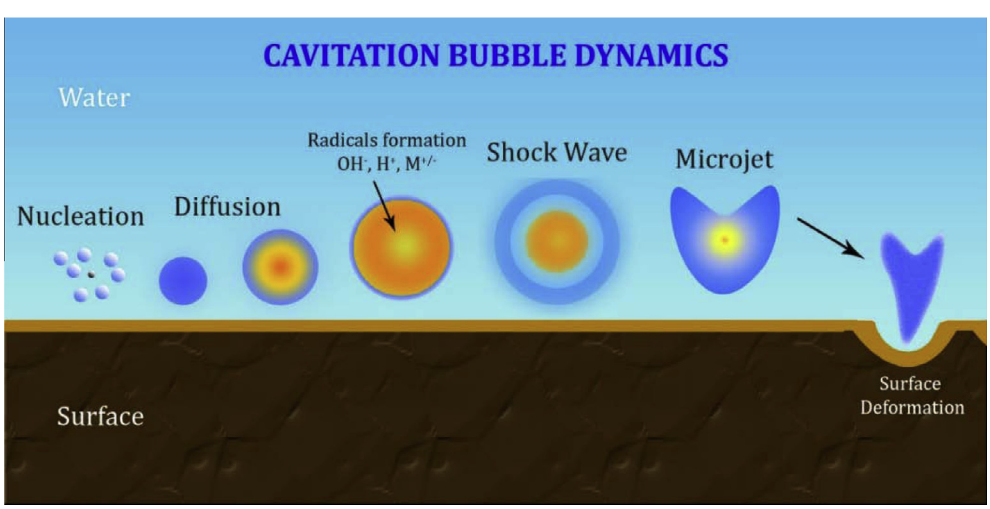

Fig. 1. The process of acoustic cavitation and its effect.