

Chemical and Physical Effects of Ultrasound: Sonoluminescence and Materials

Hangxun Xu

Final Seminar

June 21, 2011

When a liquid is irradiated with ultrasound, acoustic cavitation (the formation, growth, and implosive collapse of bubbles in liquids irradiated with ultrasound) generally occurs.^{1,2} This is the phenomenon responsible for driving chemical reactions (sonochemistry) and the emission of light (sonoluminescence).^{3,4} The implosive collapse of bubbles in liquids results in enormous concentration of sound energy into compressional heating of bubble contents. Therefore, extreme chemical and physical conditions are generated during acoustic cavitation.^{5,6} Study multibubble sonoluminescence (MBSL) and single-bubble sonoluminescence (SBSL) in exotic liquids such as sulfuric acid (H_2SO_4) and phosphoric acid (H_3PO_4) leads to useful information regarding the intracavity conditions during bubble collapse.⁷⁻¹⁴ Ultrabright sonoluminescence from MBSL in H_3PO_4 saturated with noble gases can be observed by naked eye, even in a well-lit room, as shown in Figure 1A.¹³ Surprisingly, distinct sonoluminescing bubble populations can be observed from the intense orange and blue-white emissions by doping the H_2SO_4 and H_3PO_4 with sodium salts, which provides the first experimental evidence for the injected droplet model over heated-shell model for cavitation.¹² Effective emission temperatures measured based on excited $\text{OH}\cdot$ and $\text{PO}\cdot$ emission indicate that there is a temperature inhomogeneity during MBSL in 85% H_3PO_4 (Figure 1B).¹³ The formation of a temperature inhomogeneity is due to the existence of different cavitating bubble populations: asymmetric collapsing bubbles contain liquid droplets and spherical collapsing bubbles do not contain liquid droplets (Figure 1C).¹³ Strong molecular emission from SBSL in 65% H_3PO_4 have been obtained and used as a spectroscopic probe to determine the cavitation temperatures.¹⁴ It is found that the intracavity temperatures are dependent on the applied acoustic pressures and the thermal conductivities of dissolved noble gases.¹⁴

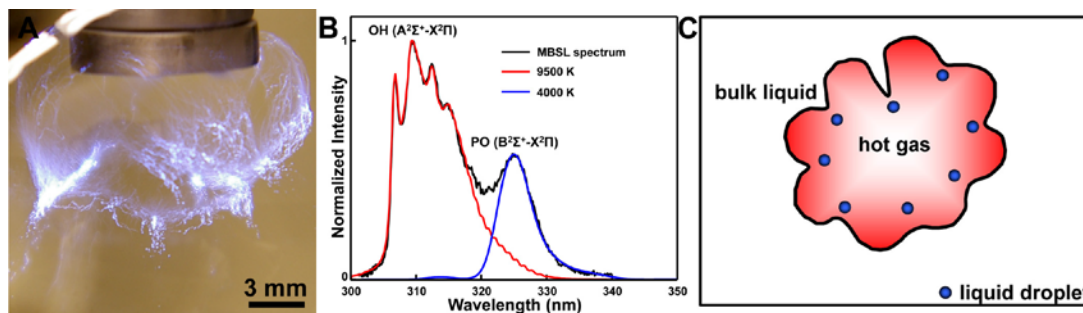


Figure 1. (A) A photograph of ultrabright sonoluminescence from 85% H_3PO_4 saturated with Xe gas. (B) Spectrum of OH and PO emission from MBSL in H_3PO_4 saturated with He and irradiated with ultrasound compared to the best fit calculated spectra. (C) A schematic illustration of the non-symmetric collapse of a bubble that involves injections of liquid droplets into the interior of the collapsing bubble.

The chemical and physical effects of ultrasound can be used for materials synthesis.^{15,16} Highly reactive species, including $\text{HO}_2\cdot$, $\text{H}\cdot$, and $\text{OH}\cdot$ (or $\text{R}\cdot$ after additives react with $\text{OH}\cdot$) are formed during aqueous sonolysis as a consequence of the chemical effects of ultrasound.^{15,16}

Reductive species can be applied to the synthesis of water-soluble fluorescent silver nanoclusters in the presence of a suitable stabilizer or capping agent (Figure 2A and 2B).¹⁷ The optical and fluorescent properties of the Ag nanoclusters can be easily controlled by the synthetic conditions such as the sonication time, the stoichiometry of the carboxylate groups to Ag⁺, and the polymer molecular weight.¹⁷ The chemical and physical effects of ultrasound can be combined to prepare polymer functionalized graphenes from graphites and a reactive solvent, styrene (Figure 2C).¹⁸ The physical effects of ultrasound are used to exfoliate graphites to graphenes while the chemical effects of ultrasound are used to induce the polymerization of styrene which can then functionalize graphene sheets via radical coupling. The prepared polymer functionalized graphenes are highly stable in common organic solvents like THF, CHCl₃, and DMF (Figure 2D).¹⁸

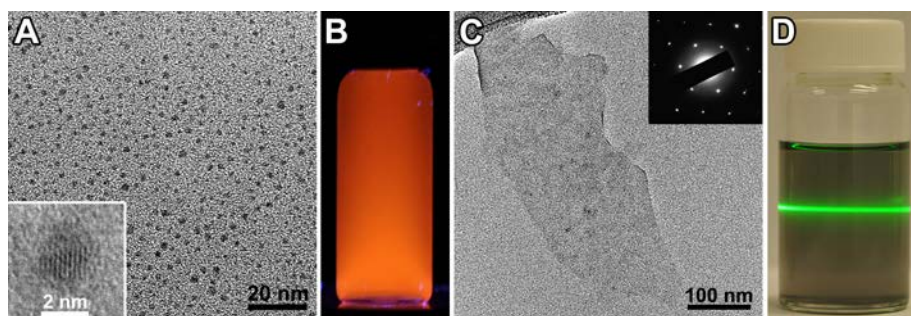


Figure 2. (A) TEM image of Ag nanoclusters after sonication for 90 min (inset shows a single magnified Ag nanocluster). (B) A Solution of the Ag nanoclusters irradiated by 365 nm UV lamp. (C) TEM image of a single-layer graphene with SAED inset confirming single-layer nature. (D) A photograph of a stable graphene solution. Tyndall effect is observed here using a green laser pointer through the graphene solution.

Ultrasonic spray pyrolysis (USP) is used to prepare porous carbon spheres using energetic alkali propiolates as the carbon precursors. In this synthesis, metal salts are generated *in situ*, introducing porous structures into the carbon spheres. When different alkali salts or their mixtures are used as the precursor, carbon spheres with different morphologies and structures are obtained. The different precursor decomposition pathways are responsible for the observed structural difference. Such prepared carbon spheres have high surface area and are thermally stable, making them potentially useful for catalytic supports, adsorbents, or for other applications by integrating other functional materials into their pores.

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