Silica Aerogels: Synthesis and Applications

Karen L. Kozlowski Materials Literature Seminar October 28, 2004

S. S. Kistler, credited with making the first silica aerogels, used the supercritical drying process to extract the solvent from the wet gel while maintaining the solid gel network, while Teichner and Nicolaon revised the time consuming wet gel process using instead the more time efficient sol-gel process, which is still used today.[1,2]

Silica aerogels are remarkable for their unique and exceptional properties as well as their wide range of applications. Their properties include high porosity, high surface area, low density, low dielectric constant, and high thermal stability.[2-4] Their qualities allow for use in the applications of insulation materials, catalyst supports, carrier materials, electronics, kinetic energy absorbers, and fillers.[3,5] The synthesis of these aerogels depend on the mechanisms used in sol-gel chemistry that lead to the wet gels, which are then dried to form aerogels (Figure 1).[6]

The manner in which the wet gel is made determines the properties of the dried aerogel. In the sol-gel process, a silica precursor is added to a solvent. The most common precursors used in silica sol-gel chemistry are tetramethoxyorthosilicate (TMOS) and tetraethoxyorthosilicate (TEOS).[7,8] They are chosen because of their small substituents which results in shorter gelation time[6]. In the presence of a catalyst, the ensuing reaction forms colloidal particles in a suspension[6]. Over time, the particles crosslink together to from a viscous gel that over time ages into a wet solid gel (Figure 1).[6]

Silica gels can be made by either a one step process or a two step process. The one step route consists of the silica precursor being mixed in a solvent with either a base or an acid catalyst, followed by hydrolysis and condensation reactions leading to the cross-linked gel.[7] Two step acid-base sol-gel reactions consist of an acid catalyzed step in which the silica precursor is prepolymerized followed by a second step of base catalyzed condensation reactions.[6] The two step procedure is preferred because it results in silica aerogels that are more porous and transparent.[8]

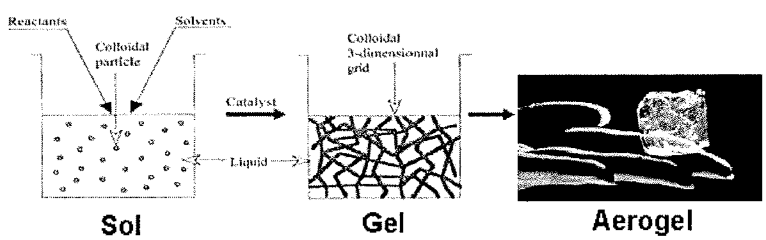

Figure 1

Once the wet gel is formed, there are three main ways to transform it into a dried gel. The method that leads to aerogels is supercritical drying, which is mainly done by adding liquid CO_2 into the gel pores and drying under elevated temperatures and pressures.[2] The gel can also be dried in air from the original solvent, resulting in a xerogel which has a dense structure.[2] Another method to dry the gel is by replacing the solvent with an alkane and drying in air, resulting in an "ambigel" (coined by Rolison et al.).[2] These ambiently dried gels are being explored more because their production is less expensive and hazardous than supercritical drying methods.[9]

Silica aerogels are useful in their native form, but there are many places along the route from silica precursor to silica aerogel that chemical modifications can occur for use in chemical, electronic, or optical applications.[10] Among these modifications are grafting of molecules onto the surface[11], and forming composites in which various colloidal metals, zeolite particles, and even polymers are added to the sol before the gelation phase.[10] Further modifications can be done to tackle the problems of the brittle nature and hygroscopicity of aerogels, such as the cross-linking of polymer precursor to the silica network[12], or precursor modifications that lead to an increased hydrophobic nature.[6, 13]

One potentially useful application for silica aerogels is its incorporation into light-emitting diodes (LEDs).[14] Because of its very low refractive index, it improves the coupling-out effiency of light from the organic emissive layer by preventing edge emission.[14]

Interest in using silica aerogels as an interlayer dielectric is also increasing.[4] There have been rapid advances made in integrated-circuit technology, resulting in a need for very low dielectric films. As circuits shrink in size, there is an increase in problems such as cross-talk and resistance-capacitance (RC) delay.[4] Silica aerogels are ideal for this situation because they have a dielectric constant lower than 2 and can be made into a thin film having the necessary gap filling and planarization characteristics.[4]

Silica aerogels have further been employed to capture cosmic dust from outer space.[15, 16] The Stardust mission of NASA has been sent to space to collect cosmic dust and comet Wild 2 particles.[15] The low density of aerogels can handle the high velocity impact from cosmic dust as well as the extreme conditions encountered in space.[15, 16] The silica aerogel sample tray assembly is shown in Figure 2. Information gathered from these particles can provide a wealth of information about the origin of our solar system and if there is the presence of life outside of Earth.[15]

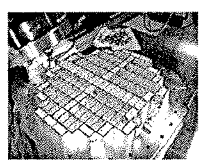

Figure 2

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