Tris-(8-hydroxyquinoline) aluminum nanoparticles prepared by vapor condensation

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Tris-(8-hydroxyquinoline) aluminum (AlQ₃) spherical nanoparticles of the average size varying from 50 to 500 nm were synthesized by vapor condensation. The surface of the nanoparticles is quite sleek and smooth like that of pearls. The x-ray diffraction patterns reveal that the nanoparticles have an amorphous structure. The chemical bonding of AlQ₃ is preserved in the nanoparticles even after evaporation at 410 °C. The photoluminescence spectra of the nanoparticles show a broadened peak varying from 4500 to 7000 Å, with the maximum intensity at about 5380 Å. The maximum intensity increases as the particle size decreases, owing to the large specific surface area. © 2003 American Institute of Physics. [DOI: 10.1063/1.1591249]

In the past decades, the trend of technological development in electronics has been to make the device smaller and more powerful. This requires that each of the constituent materials be operated more efficiently and cost effectively. Since the discovery of the buckyball and carbon nanotubes, materials have been developed to be operated more efficiently and cost effectively. This requires that each of the constituent materials be operated more efficiently and cost effectively. Since the discovery of the buckyball and carbon nanotubes, materials have been developed to be operated more efficiently and cost effectively. This requires that each of the constituent materials be operated more efficiently and cost effectively. Since the discovery of the buckyball and carbon nanotubes, materials have been developed to be operated more efficiently and cost effectively. This requires that each of the constituent materials be operated more efficiently and cost effectively. Since the discovery of the buckyball and carbon nanotubes, materials have been developed to be operated more efficiently and cost effectively. This requires that each of the constituent materials be operated more efficiently and cost effectively. Since the discovery of the buckyball and carbon nanotubes, materials have been developed to be operated more efficiently and cost effectively. This requires that each of the constituent materials be operated more efficiently and cost effectively. Since the discovery of the buckyball and carbon nanotubes, materials have been developed to be operated more efficiently and cost effectively. This requires that each of the constituent materials be operated more efficiently and cost effectively. Since the discovery of the buckyball and carbon nanotubes, materials have been developed to be operated more efficiently and cost effectively. This requires that each of the constituent materials be operated more efficiently and cost effectively. Since the discovery of the buckyball and carbon nanotubes, materials have been developed to be operated more efficiently and cost effectively. This requires that each of the constituent materials be operated more efficiently and cost effectively. Since the discovery of the buckyball and carbon nanotubes, materials have been developed to be operated more efficiently and cost effectively. This requires that each of the constituent materials be operated more efficiently and cost effectively. Since the discovery of the buckyball and carbon nanotubes, materials have been developed to be operated more efficiently and cost effectively. This requires that each of the constituent materials be operated more efficiently and cost effectively. Since the discovery of the buckyball and carbon nanotubes, materials have been developed to be operated more efficiently and cost effectively. This requires that each of the constituent materials be operated more efficiently and cost effectively. Since the discovery of the buckyball and carbon nanotubes, materials have been developed to be operated more efficiently and cost effectively. This requires that each of the constituent materials be operated more efficiently and cost effectively. Since the discovery of the buckyball and carbon nanotubes, materials have been developed to be operated more efficiently and cost effectively. This requires that each of the constituent materials be operated more efficiently and cost effectively. Since the discovery of the buckyball and carbon nanotubes, materials have been developed to be operated more efficiently and cost effectively. This requires that each of the constituent materials be operated more efficiently and cost effectively. Since the discovery of the buckyball and carbon nanotubes, materials have been developed to be operated more efficiently and cost effectively. This requires that each of the constituent materials be operated more efficiently and cost effectively. Since the discovery of the buckyball and carbon nanotubes, materials have been developed to be operated more efficiently and cost effectively. This requires that each of the constituent materials be operated more efficiently and cost effectively. Since the discovery of the buckyball and carbon nanotubes, materials have been developed to be operated more efficiently and cost effective...
boat temperature $T$. For simplicity, the boat temperature $T$ is set at 410 °C, and the dependences of particle size on $P_{Ar}$ and $d$ are considered separately. At fixed $T$ and $d$, the average size of particles increases significantly and the range of size distribution becomes larger when $P_{Ar}$ increases, as shown in Fig. 3(a). Similarly, at fixed $T$ and $P_{Ar}$, the average size also increases when $d$ increases, as shown in Fig. 3(b).

In general, the boat temperature should be controlled at 400–410 °C in order to form the nanoparticles when $P_{Ar}$ is higher than 133 Pa. When the pressure is lower than 133 Pa, the boat temperature must be carefully controlled. For example, when $P_{Ar}$ = 13.3–133 Pa, nanoparticles can be obtained only at $T$ = 405–410 °C.

Although the dependence of the particle size on $P_{Ar}$ and $d$ has been reported for inorganic nanoparticles, it is surprising that the AlQ$_3$ molecule with a molecular weight much larger than that of Ar atom also exhibits similar behavior. This can be understood by the collision mechanism during the evaporation. The AlQ$_3$ molecules collide with the Ar atoms and gradually lose their energy. Since the substrate is cooled down to −196 °C by liquid nitrogen, it is believed that this temperature is low enough to stop nanoparticles from coalescing on the substrate. The particle size is related to the energy loss, which can be realized by the ratio between the atomic weights of evaporated material and Ar.

For those inorganic materials whose atomic weights are comparable to that of Ar, their kinetic energy can be reduced by colliding with the Ar atoms. For instance, the atomic masses of Si and Ar are 28 and 40, respectively. The ratio of the atomic masses is 0.7. The molecular weight of AlQ$_3$ is 459, and the ratio becomes about 11.5. This value is much greater than that for Si, and the particle size should be larger under the same condition. Previously, the sizes of Si nanoparticles prepared at $P_{Ar}$ = 133 Pa and $d$ = 10 cm are about 4–8 nm. The sizes of the AlQ$_3$ nanoparticles prepared in this study under the same condition are about 50–100 nm. These results agree with the prediction.

AlQ$_3$ powder may exist in a variety of phases, such as α, β, and γ phases, and their x-ray diffraction (XRD) patterns are quite different after evaporation. From the XRD patterns illustrated in Fig. 4, the AlQ$_3$ powder has good crystallinity before evaporation, but the nanoparticles become amorphous after sublimation. To check if the AlQ$_3$ molecules are decomposed during evaporation, the chemical bondings of AlQ$_3$ in the nanoparticles, thin film, and original powder were examined by Fourier-transform infrared spectrum (FTIR). The FTIR test samples were prepared by growing AlQ$_3$ nanoparticles directly on a potassium bromide (KBr) pellet. A thin film of thickness 1200 Å was also deposited on another KBr pellet at a pressure of 1.33 × 10$^{-3}$ Pa and a deposition rate of 3 to 5 Å/s controlled by a quartz monitor. Except for the peaks due to CO$_2$ and H$_2$O, all the other absorption peaks between 600 and 2000 cm$^{-1}$
absorption peaks of the nanoparticles and the thin film are found in good agreement with the reported results.\textsuperscript{19} The absorption peaks of the nanoparticles and the thin film are consistent with those of the AlQ\textsubscript{3} powder, indicating that the bonding of the molecule is preserved even after evaporation at 410 °C.

The PL spectra were obtained by exciting with a He–Cd laser of a wavelength 325 nm and a power 50 mW. The He–Cd laser beam was focused on an area of about 1 mm\textsuperscript{2} to ensure that all the samples had a similar irradiated area. The PL spectra of the AlQ\textsubscript{3} nanoparticles with diameters of 50–100 and 100–300 nm are shown in Figs. 5(a) and 5(b), respectively. In addition, that of an AlQ\textsubscript{3} thin film of a thickness 1200 Å is also displayed in Fig. 5(c) for reference. The PL peaks show the same maximum intensity at about 5380 Å and are broadened ranging from 4500 to 7000 Å. The maximum PL intensities of the nanoparticle samples are higher than that of the thin film, and the maximum PL intensity increases as the particle size decreases.\textsuperscript{14,15} For ultrafine particles, they have very large specific surface area and surface energy. The larger specific surface area of the smaller nanoparticles increases the optical absorption and further enhances the intensity of luminescence. It is noted that the chemical bonding and surface morphology of the AlQ\textsubscript{3} nanoparticles are preserved after aging in air at room temperature for more than one week, according to the FTIR spectra and FEGSEM images. However, degradation of the PL intensity occurs, and the degradation is more pronounced for the nanoparticles than for the thin film due to the larger specific surface area.

In summary, AlQ\textsubscript{3} nanoparticles of the average size varying from 50 to 500 nm were synthesized by vapor condensation. The nanoparticles are spherical and have an amorphous structure. The chemical bonding is preserved after evaporation. The larger specific surface area of smaller nanoparticles increases the optical absorption and further enhances the intensity of photoluminescence. Related work will be of great interest for future study.

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