

Alumina

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Accepted 05 November 2013, Available online 01 December 2013, Vol.3, No.5 (December 2013)

Abstract

Aluminium oxide (alumina or Al_2O_3) is currently one of the most useful oxide ceramics, as it has been used in many fields of engineering such as coatings, heat-resistant materials, abrasive grains, cutting materials and advanced ceramics. This is because alumina is hard, highly resistant towards bases and acids, allows very high temperature applications and has excellent wear resistance. Alumina is also an inert substance, and at room temperature, it is insoluble in all ordinary chemical reagents. These qualities make it a smart material for variety of applications ranging from aerospace up to medical implants and health care. The long history of research on most intrinsic properties of alumina are known, but even today a significant part of research work deals with alumina materials science on a fundamental level. The main reason is arguably the complexity and usefulness of the alumina polymorphs. Now day's nanotechnology is playing an important role to establish relationship between different polymorphs of alumina, novel low temperature synthesis and characterization techniques. The aim of this review is to give a short exposure on alumina crystalline phase including synthesis and applications.

Keywords: Alumina, Polymorphs, Energetic bombardment, nanotechnology

1. Introduction

Alumina (Al_2O_3) or Aluminium Oxide is the only oxide formed by the metal aluminium and occurs in nature as the minerals corundum (Al_2O_3); diaspore ($Al_2O_3 \cdot H_2O$); gibbsite ($Al_2O_3 \cdot 3H_2O$); and most commonly as bauxite, which is an impure form of gibbsite. The precious stones ruby and sapphire are composed of corundum (and thus also natural forms of alumina), getting their colors by small amounts of impurities (Davis *et al.*, 2010). Although the naturally occurring corundum, ruby and sapphire are also sometimes referred as alumina, but the proper use of the term is limited to the material that is derived from bauxite and employed in the production of aluminium, industrial ceramics, and chemical processing (Historical Milestones, 2002). The history of alumina is linked to the alum, forms wherever schistose or clayey earth comes in contact with sulphuric acid as a result of sulphurated minerals or volcanic smoke. Alum is a compound aluminium and potassium disulphate ($KAl(SO_4)_2 \cdot 12H_2O$), and was known to the Sumerians, Egyptians, Greeks and Romans who used it for a wide variety of applications such as medicine for stopping blood flow, as wound healing substance, as mordant for wool dye, as an anti-inflammatory product, and as fire retardant substance etc.

Now day's nanotechnology is actively involved in the production of nanostructures from bottom up approach. These new Nano-engineered materials show different properties due to quantum mechanical effects comparing to their bulk counterpart and has structures size in the range of typically 1-100nm. A smaller particle size enables a much larger surface area for molecular collisions and therefore increases the rate of reaction, making it a better catalyst and reactant. Finer abrasive grains would enable finer polishing, and this would also give rise to new applications areas like nano-machining and nano-probes. In terms of coatings, the use of nano-sized alumina particles would significantly increase the quality and reproducibility of thin films. Zero dimension alumina nanoparticles has shown important applications in ceramic industry and can be used as an abrasive material, in heterogeneous catalysis, as an absorbent, as a biomaterial and as reinforcements of metal-matrix composites (MMCs) (Ganguly *et al.* 2003). Furthermore *activated alumina* is a porous, granular substance that is used as a substrate for catalysts and as an adsorbent for removing water from gases and liquids. *Smelter-grade alumina* accounts for 90 percent of all alumina produced; it is transported to aluminium plants, where it is electrolyzed into aluminium metal. *Calcined alumina* is made into a variety of ceramic products, including spark-plug insulators, integrated circuit packages, bone and dental

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implants, laboratory ware, sandpaper grits and grinding wheels, and refractory linings for industrial furnaces. These products exhibit the properties for which alumina is well known, including low electric conductivity, resistance to chemical attack, high strength, extreme hardness (20 to 30 GPa), and high melting point (2,050°C, or 3,700°F) (Hassan *et al.*, Gupta *et al.*, 2004). The toughness of alumina can be improved by the addition of zirconia particles or silicon carbide whiskers, making it suitable for industrial cutting tools. Also, the normally opaque material can be made translucent by adding small amounts of magnesia. Translucent alumina is employed as the gas container in high-pressure sodium-vapor streetlamps (Hassan *et al.*, Gupta *et al.*, 2004).

2. Crystal Structure of Alumina

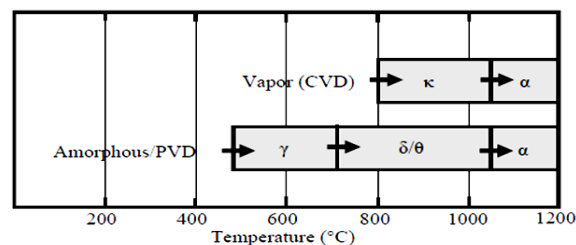
The alumina exists with different phases depending on the alumina purity and its mechanical and physical properties. The most important, and common, alumina polymorphs (crystalline phase) are denoted as α , γ , θ , and κ (Levin *et al.*, 2012). In addition to these, there are reports on more than twenty other crystalline phases. The α phase is thermodynamically stable polymorph and occurs naturally as corundum or sapphire, while the other phases are metastable in bulk form (but can still be produced in certain processes where thermal equilibrium is not reached, e.g., thin film growth). The differences in properties between the phases make them important in different applications (Dorre *et al.*, Hubner *et al.*, 1984). For example, the α and κ phases are widely used as wear resistant coatings due to their high hardness and thermal stability, while γ and θ -alumina are more suited for catalytic applications due to their lower surface energies, leading to larger active surface areas available for catalytic reactions.

Crystalline phase are responsible for different properties of alumina yet dopants also effects on alumina phase stability. As an atom of the alumina lattice is substituted by another element, the energy of the lattice would change due to differences in chemical bonding and/or size of the substituting atom compared to the original. It has been shown that it is possible to increase or decrease the relative stability of the α -alumina and even make it less stable than the θ alumina by dopant atoms (Dorre *et al.*, Hubner *et al.*, 1984). Consequently, the results predicted that it should be possible to control the thermal stability of doped alumina thin films in order to increase the thermal stability of metastable alumina phases. However It is difficult, to predict the exact effect of doping in an experimental situation, since it was also shown that phase separations of the doped alumina are energetically favored, and will most likely occur at elevated temperatures.

The common alumina polymorphs formed within typical synthesis temperatures range from room temperature up to about 1000°C. This complicates the study and growth of alumina, since it becomes difficult to control the process so that the desired phase is achieved. All alumina phases are involved in transformation

sequences, which all have in common that they end in α phase alumina at high temperature. Transformations into α phase are irreversible and typically take place at above 1000°C (Gitzen *et al.*, 1970).

Table 1. Typical transformation of metastable polymorphs into stable α alumina



2.1. α -alumina

The α phase of alumina is also known as corundum (the name comes from the naturally occurring mineral corundum, which consists of pure α - Al_2O_3). It is transparent and uncolored substance. It is not only used in materials science, but occurs also as gemstones. The gem known as ruby is α -alumina doped with small amounts of chromium, while the gemstone sapphire is actually α -alumina doped with iron and titanium. Like all alumina phases the α phase is highly ionic with calculated valences of $+2.63e$ and $-1.75e$ for aluminium and oxygen respectively. Thus the chemical bonds between ions are almost purely ionic or electrostatic (Wyckoff *et al.*, 1964).

The α alumina is the only stable alumina phase at all temperatures. It has a trigonal (rhombohedral) structure (R-3c) and is usually described as ABAB stacking of oxygen planes along the c (111) direction (Xu *et al.*, Ching *et al.*, 1991). Rhombohedral phase of alumina can be described as a hexagonal close packed (hcp) oxygen sublattice, in which the aluminium atoms, or ions, occupy two thirds of the octahedral interstices, i.e., they have six oxygen nearest neighbors, so that there is only one coordination (octahedral) for aluminium and one for oxygen (with four surrounding aluminium ions) exists (Gains *et al.*, Skinner *et al.*, 1997).

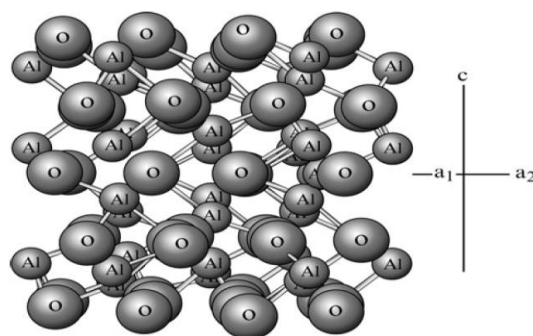


Figure 1. The aluminium atoms occupy two-thirds of the octahedral interstices in a hexagonal close packed array of oxygen atoms, which is distorted because the octahedral share faces in pairs.

The thermodynamic stability of α -alumina makes it the most suited phase for use in many high temperature applications. Other important characteristics of α -alumina are chemical inertness and high hardness. The elastic modulus and hardness are measured to be ~ 440 and ~ 28 GPa (Oliver *et al.*, 1992), respectively. These can be compared to diamond, which have values of ~ 1100 and ~ 100 GPa, to TiN with values similar to those of α -alumina, and to metallic Al which has values of ~ 70 and ~ 0.3 GPa (Oliver *et al.*, Pharr *et al.*, 1992). Combined, these properties have made α -alumina important in wear resistant and high-temperature diffusion barrier coatings. Other uses of α -alumina is in electronics, where it is used, as an insulator due to the wide band gap of 8.8 eV, and in optics, since it is completely transparent and stable at high temperature (Martin *et al.*, 2005).

2.2. θ -alumina

The θ phase of alumina is metastable and transforms into α phase at about 1050°C (Levin *et al.*, 2012). It is less dense than the α phase with a density of about 3600 kg/m^3 compared to 4000 kg/m^3 for α -alumina (Levin *et al.*, 2012). The structures of all alumina phases are built up around (slightly distorted) close-packed oxygen lattices and while α phase has an hcp framework, the θ structure is based on an fcc oxygen lattice (Zhou *et al.* 1991). Within this oxygen framework, half the aluminium ions occupy octahedral interstitial sites and half occupy tetrahedral (with four oxygen neighbors) sites. This is also in contrast to α phase.

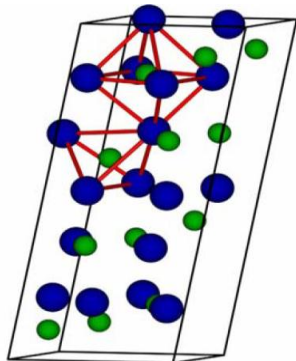


Figure 2. The θ -alumina, large spheres represent O_2 atoms and small one represents Al atoms.

The oxygen ions have three different possible surroundings, each of which is occupied by one third of the oxygen ions. Two of these oxygen sites have three aluminium atoms in nearest neighbors and the third has four. The structure is monoclinic, belonging to space group C^2/m , and the unit cell contains four formula units (20 atoms) with lattice parameters. θ alumina is a structural isomorph of $\beta\text{-Ga}_2\text{O}_3$ and, interestingly, gallium oxide can also form the corundum structure. There are not as many investigations made on the θ phase as on α -alumina. It is clear, though, that it is highly ionic and insulating with a band gap of 7.4 eV (Franchy *et al.*, Schmitz *et al.*, 1997).

2.3. γ -alumina

Due to low surface energy and, hence, high surface area, γ alumina is extensively used as catalyst supports. The low surface energy also means that the γ phase is surface energy stabilized when the surface area is high relative to the bulk volume, e.g., for small grain sizes (Vasefi *et al.*, Parvari *et al.*, 2010). The consequences with high-temperature applications a problem with the use of the γ phase is that it transforms into θ at $700\text{-}800^\circ\text{C}$ (McHale *et al.*, 1997). This has led to the experimental research on doping of alumina to increase its thermal stability. The γ -alumina structure has two main similarities with the θ phase, the fcc oxygen lattice and the mixture of octahedral and tetrahedral coordinated aluminium ions. However, the exact structure is not well defined. It is commonly believed that the structure can be described as a defect cubic spinel with space group $Fd\text{-}3m$ and is based on an fcc, ABCABC stacking of oxygen. The aluminium ions more or less randomly distributed between octahedral and tetrahedral sites (Jiang *et al.*, Music *et al.*, 2010). Each unit cell contains 32 oxygen and $64/3$ aluminum ions to fulfill stoichiometry. The aluminum ions occupy both octahedral and tetrahedral positions, but the relative partial occupancy in each position is still a matter of dispute.

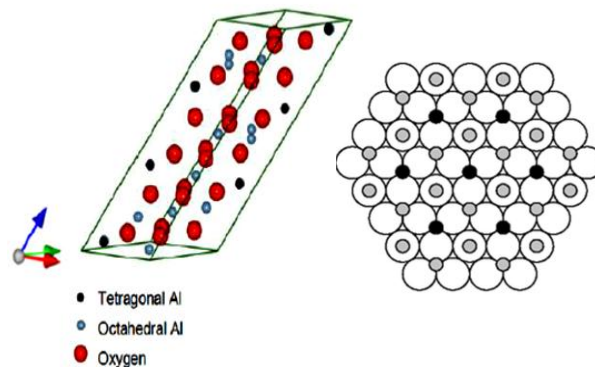


Figure 3. The fcc structure for O_2 lattice and the octahedral-tetrahedral structure for Al lattice

3. Synthesis of alumina

Marggraf first isolated 'alumina' by extracting it from natural clay using sulphuric acid in 1754 and the word "alumina" was first coined for the substance by Guyton de Morveau in 1761 (Historical Milestones, 2002). This was followed by the discovery of earth rich in alumina near Les Baux (region of Arles- A medieval kingdom of eastern and southeast France) by Berthier who named it Bauxite. Manufacturing of alumina was first started in 1860 in the South of France by using the *Sainte-Claire Deville* process that consisted of attacking bauxite by sodium carbonate followed by the precipitation of alumina hydrate. Other important developments in the history of the development of alumina were the perfection of the process of electrolyzing alumina into aluminium in 1886 by *Hérault* in France and by *Hall* in the US (Historical Milestones, 2002). This process is still used today. The other important development was the perfection of the process of

extracting alumina from bauxite by an Austrian named Bayer in 1888. The Bayer Process, named after its inventor, is still the most widely used process in the manufacturing of alumina with a purity of 99.6-99.9%. Furthermore Sumitomo Chemical Co. Ltd. refines the Bayer process and introduces hydrolysis of aluminium alkoxide method for manufacturing highly pure, commercial grade, nanosized alumina powder with present production capacity aiming 1500 tons per year. In this process high purity aluminium alkoxide is synthesized from aluminium metal and alcohol, and hydrated alumina is produced by hydrolysis of alkoxide, and finally high purity alumina is obtained by calcination (SUMITOMO KAGAKU, 2007).

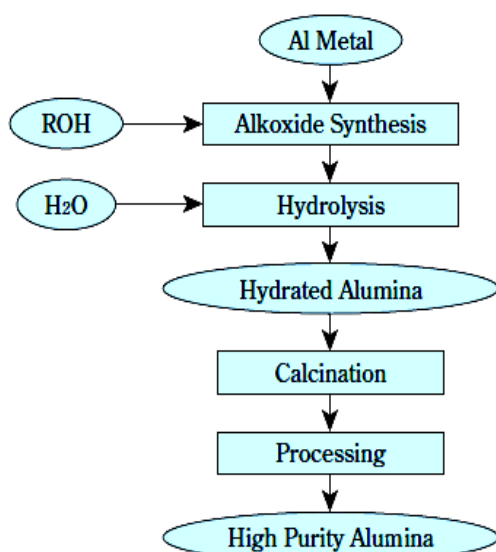
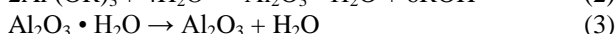
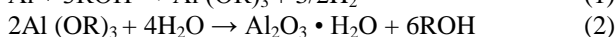
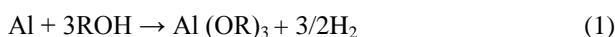


Figure 4. Schematic process of alkoxide method to obtain high purity alumina

In addition, it is important to avoid rigged agglomerates during drying. Because the hydrolysis rate for aluminium alkoxide is extremely fast, it produces fine particle hydrated alumina which easily becomes rigid agglomerates. α - Al_2O_3 , which is a stable phase at high temperatures, is obtained by calcination of hydrated alumina (boehmite) via γ , δ , θ - Al_2O_3 (intermediate alumina). The transition to α - Al_2O_3 from the intermediate alumina requires high temperatures of over 1200°C , because it needs rearrangements of the oxygen packing (cubic closest-packed structure or hexagonal closest-packed structure) (Martin *et al.*, 2005). The generation of α crystal nuclei is a rate determining step for α phase transition, and that the density of α crystal nuclei is low. But once nuclei are generated, a sudden grain growth occurs because of mass transfer from the surrounding intermediate alumina, and dendritic α - Al_2O_3 particles of micron size are obtained (SUMITOMO KAGAKU, 2007). Recently Tok *et al.* and Zhao *et al.* (2013) demonstrated a

novel flame spray pyrolysis method for synthesis of alumina nanoparticles by using anhydrous AlCl_3 powder (purity 99.6%) as the starting material. The flame spray pyrolysis (FSP) apparatus consists of an in-house manufactured heating chamber, a flame gun, and collection reactor with water cooling and an exhaust gas system. The spray gun, which is mounted at the front of a collection reactor, was operated with acetylene (65 PSI) and oxygen (70 PSI) (Tok *et al.*, 2013). The anhydrous AlCl_3 powders together with nitrogen gas were injected into the flame gun using the heating chamber at 300°C and directly sprayed into the collection chamber. Combustion occurred at less than 2000°C . In order to remove residual water and obtain fully crystallized particles with small particle size, the as-sprayed Al_2O_3 nano-particles were calcined at 1100°C for two hours using a heating rate of $10^\circ\text{C min}^{-1}$. Cooling rate was set to $50^\circ\text{C min}^{-1}$ to reduce the possibility of agglomeration of nano-alumina powders. In an another pioneer work reported by Piriya Wong *et al.* (2012) alumina nanoparticles were synthesized in liquid by using short pulse Nd:YAG laser (laser ablation) with the pulse width in the range of nanoseconds. Al target was used as a starting material for laser ablation process. A plasma plume is induced at the surface of target by laser pulse mainly as a result of inter-band transition, multi-photon absorption and inverse Bremsstrahlung in liquid phase and nanoparticles are formed after condensation of plume (Piriya Wong *et al.*, 2012). The simplest method to produce alumina nanoparticles is the self-propagating combustion synthesis. In this alternative approach, nitrate starting powders are dissolved in H_2O and urea ($\text{CH}_4\text{N}_2\text{O}$) is added. Urea works as oxidizing agent and hence fuel to propel the reactions. When this mixture is boiled, dehydrated, and dried, it forms a hygroscopic precursor to varieties of alumina doped materials (Schneider *et al.* 2001).

4. Alumina research field

4.1. Alumina as a wear-resistant coating

Over the last decades, thin films have found an increasingly important application as wear-resistant coatings on, e.g., cutting tools. An important example is TiN (Ruppi *et al.*, 2005), which dramatically increased the life time of cutting tools. A drawback with TiN is the limited oxidation resistance at elevated temperatures. Later on this problem was dealt with by introducing Al into the TiN lattice and thereby promoting the formation of a protective alumina layer through oxidation. Alumina has Young's modulus 403 GPa as well as high hardness factor 3000 kg mm^{-2} , which make it suitable for high impact bearing abrasive coatings (Ruppi *et al.*, 2005).

4.2. Role of energetic bombardment

In order to lower the growth temperatures of crystalline alumina coatings, Zywitzki *et al.* (1993) used pulsed DC sputtering and grew single-phase α -alumina films at 760°C , significantly lower than both the CVD

temperatures and the θ - α transformation temperature. By ionized PVD Schneider *et al.* (1997) grew κ -alumina at temperatures as low as 430°C, by applying a negative bias on the substrate to increase the energy of the depositing species and to bombard the growing film with sputtering gas ions. Kyrlyov *et al.* (2004) used plasma assisted CVD to grow α -alumina at 580°C. An important reason for these rather dramatic decreases in growth temperatures is energetic bombardment, which can be more or less controllably used in deposition situations involving plasma. Bombardment during growth can strongly influence the structure and properties of thin films. Recently a few studies have appeared, studying the role of energetic bombardment during cathodic vacuum arc deposition of alumina thin films. The works show that it is possible to promote crystalline phase formation and the deposition temperature of α -alumina can be decreased from 800 - 900°C to 600 - 700°C by applying a high substrate bias (more than 100 V) (Kyrlyov *et al.*, 2004).

4.3. Growth of alumina

Another fundamental area of alumina growth has also been introduced recently. At initial growth, surface energies are of great importance, since the relative surface area of small grains is large. McHale *et al.* (1997) measured the surface energy of γ and α alumina and concluded that for surface areas of above 125 m²/g, the γ phase is energetically favored due to its much lower surface energy (for a spherical γ alumina grain this value corresponds to a grain diameter of about 13 nm). These measurements, which confirmed the predictions made by Blonski *et al.* and Garofalini *et al.* (1993) by atomistic computer simulations, lead to the suggestion that the metastable alumina surface energy stabilized at initial growth, i.e., they form because they are thermally stable when the grain size is small enough. In order for a transformation to the α phase to occur, the growth temperature must be raised to initiate bulk diffusion or the growth surface must be bombarded. Rуппи *et al.*, (2005) has shown that by controlling the nucleation step high quality α - or κ - alumina can be grown by CVD at 1000°C. This demonstrates that the nucleation step is also highly important at high temperatures.

4.4. The effect of doping on alumina phase stability

Due to the application of the metastable alumina as catalysts or catalyst supports, there is an interest in stabilizing them with respect to the α phase. A natural course of action, taken by a number of researchers, would be to investigate the effects of dopants on the relative phase stability. Most dopants attempted in previous works seem to retard the γ - α transformation (e.g., Cr, Cs, B, La, Ce, Ba, Sr, Ca, Er, Y) (Clarke *et al.*, 1998), but not stop it. Researchers suggest that the reason for these effects is that the ions block diffusion and thus delays and/or slows the transformation towards the stable α phase. However, they do not report where the dopants are situated within the material and thus questions arise: is diffusion blocking

actually the governing mechanism for transformation retardation? If it is, where does it take place? What effect on alumina phase stability do the dopants have if they are substituted into the lattice? (Okada *et al.*, 2000).

5. Applications of alumina

More than 90% of alumina produced worldwide is utilized in the production of Aluminium. This is because converting the naturally occurring bauxite into alumina is the necessary first step before it can be converted into Aluminium. It is estimated that over 4 million tons of alumina is used in material applications worldwide (excluding the alumina used for aluminium production). The varied applications of alumina are due to its abundance and its multiple forms as well as its properties of stability, purity, refractoriness, and chemical inertia.

5.1. Display devices

In recent years, plasma display panels (PDP) have been receiving more attention as large flat panel displays that are thin with flat screens. The principle of operation for PDPs is the emitting of phosphor excited by the vacuum ultraviolet (VUV) that was generated by Xe molecular beam radiation with a wavelength of 147 nm and the Xe resonance line with a wavelength of 172 nm (Matsushita Electric, 2004). In addition, in the cold cathode fluorescent lamps that are widely used as backlights of LCD, Red, Green and Blue phosphors are excited by ultraviolet ray with a wavelength of 254 nm which are emitted by mercury atoms. Among these phosphors, it is known that BaMgAl₁₀O₁₇:Eu²⁺ (BAM) is used as commercial blue phosphor. Generally, aluminate phosphors including BAM are typically manufactured by mixing high purity alumina, Ba⁻, Mg⁻, Eu⁻ compound, and fluoride flux as starting materials and calcining the mixture. It is usually called solid reaction method. (Tokyo Kagaku Kenkyusho Co., Ltd (2004).

5.2. Separation Membrane Applications

Using chemical resistance and heat resistance properties of alumina, α -Al₂O₃ porous bodies are used in the applications such as ultrafiltration, gas separation membranes. Among the gas separation membranes, the hydrogen splitting membranes are incorporated in to a hydrogen production process based on the steam-reforming reactions. (Noritake Co. Ltd., 2005).

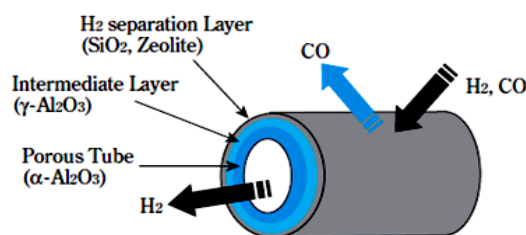


Figure 5. Schematic of Hydrogen separation element

The configuration of hydrogen splitting membranes is based on a structure that provides a γ - Al_2O_3 intermediate layer on a pipe-shaped porous α - Al_2O_3 support substrate and, forms a silica, zeolite or palladium layer with hydrogen separation function on top. To get high performance of nano pore-sized α - Al_2O_3 layer, it is required to control both pore diameter according to the application and a sufficient porosity for assuring the flow rate of the fluid (moreover, assuming that the particles are closest packed, the pore diameter is approximately 1/5 of the grain diameter). Krell *et al.* and Ma *et al.* (2003) have reported α - Al_2O_3 layer had porosity of approximately 40% and an average pore diameter of 10–60 nm by dip-coat method using nano sized α - Al_2O_3 slurry. (Noritake Co. Ltd., 2005).

5.3. Data Storage

The edge-shape particles of alumina are used in magnetic tape additives and abrasives for precision lapping and polishing abrasives of metal and plastics. Magnetic tapes are widely used as a recording medium for consumer use, broadcast use and industrial use because of its high reliability, high volume recording density, high transfer speed and other characteristics, and there has been a focus on magnetic tapes that can store large volumes of data in recent years (Shibata *et al.*, 2003). Since the magnetic layer of magnetic tape passes rapidly over a magnetic head and is subjected to a rigorous state of abrasion, α - Al_2O_3 is added to the magnetic layer to increase the abrasion resistance of the magnetic layer and clean the adhesion materials (for example Fe and C) to prevent a magnetic head blockage (Shibata *et al.*, 2003).

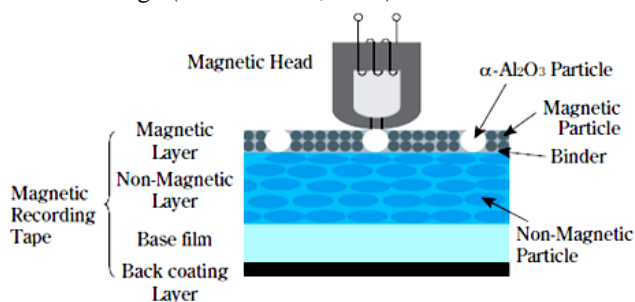


Figure 6. Schematic of data storage device

5.4. Electronics and Insulation

Alumina is widely used in the electronics industry for passive components such as interconnection, resistances, and capacitors and is specifically employed in applications such as substrates for hybrid circuits, multi-layer interconnection circuits, materials for type II condensers, and hyper frequency resonators (mobile phones). The dielectric and excellent thermal shock properties of alumina make it an excellent choice as an insulating material. For applications in very high frequencies (UHF), high purity dense alumina, fired at temperatures above 1600°C, is generally used. Examples are applications for television or satellite transmitter tubes or for microwave

generators for heating, or for powerful lasers (Historical Milestones, 2002).

5.5. Mechanical and chemical Ceramics

Due to their excellent mechanical properties, alumina based ceramics are being increasingly used as a substitute material for several applications. These include the use of ceramic for abrasive and cutting tools. Alumina-based ceramics are also used for making extrusion and sanding nozzles and for parts of machinery (particularly in the mining industry) where wear resistant qualities are critical. They are also used for making blades and some friction parts such as wear-resistant seals in piston engines. However Alumina-based Ceramic filters are chemically inert and can be manufactured with fine porosity. Due to their resistance to a wide-range of chemical attacks, the material is also used for chemical storage and transportation of aggressive products. Alumina is used for coating titanium-oxide that is an important pigment for paints, paper and plastics to inhibit its catalytic properties. It is also used for water treatment and paper manufacturing.

5.6. Bio Medical

Alumina is also an inert substance, and at room temperature, it is insoluble in all ordinary chemical reagents. It also has excellent wear resistance and can be polished to high surface finish. These qualities make it useful as a biomaterial. For example, alumina is used for artificial joint replacements; porous alumina is used as a 'bone spacer' and for teeth implants. In the biomedical field, alumina is also used for cochlear implants (hearing aids). In the more general field of medical instruments, ceramics are also used to manufacture medical tubes and other scientific, medical products (Park *et al.* 2002).

5.7. Refractory and Enameling

Another major use of alumina is in the manufacturing of refractories. Refractories are required to resist compression, erosion, creeping, thermal shock, chemical attack, vitreous dissolution and heat loss at ever higher temperatures. These requirements have necessitated the use of greater quantities of alumina as a constituent in refractories. As a result, a quarter of all alumina production (less that used in Aluminium production) goes into refractories. Alumina also use as an enameling coating, given to the surface of insulators and other ceramic materials like tiles. Alumina contributes to adherence to metal or ceramic, opacity and resistance to corrosion and to scratching in the enameling process. Enameling is also used to make decorative items (Historical Milestones, 2002).

Conclusion

As we seen in this review alumina is still under subject of research due to its unstable crystalline structures. This

behavior of alumina leads to differences in material properties thus application part too. The study of alumina is of great importance because now day's alumina covers large volume products in the chemical market and its usefulness as a 'stand-alone' material is stepping stone in the production of aluminium. On the scale of nanometer, alumina properties also affected by quantum confinement, volume effect, quantum tunnel effect etc. as a result of ultrafine alumina contains corrosion resistance, high temperature resistant, high hardness, high strength, good abrasion and oxidation resistance, insulation properties. Nanotechnology becomes a useful tool that helps in development of theoretical as well as experimental relationship between different alumina polymorphs. In conclusion nanoengineered alumina fulfills all criteria to be a future material.

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