Silicon carbide: structure, uses and history

2. 1 Silicon Carbide

2. 1. 1 Historic Overview

Silicon carbide as a material that precedes our solar system, travelling through interstellar space for billions of years, generated inside the fiery nuclear hearts of carbon rich red giant stars and in the remnants of supernovae (Davis, 2011). As a synthesized material it was first discovered by the Swedish scientist Jöns Jacob Berzelius in 1824 during his pursuit to synthesize diamonds. Sixty years later, Eugene and Alfred Cowles, invented the electric smelting furnace in 1885 (Cowles and Cowles, 1885). Edward Goodrich Acheson based on Cowles invention, created the first process to produce SiC (silicon carbide) while experimenting to find an alternative suitable mineral to substitute diamond as an abrasive and cutting material. The synthetic mineral created by the process was characterized by great refractability and hardness (Saddow and Agarwal, 2004). During the production of SiC crystals, Acheson found hexagonal crystals inside his patented reactor and sent a sample to Professor B. W. Frazier were it was discovered that although the crystals were all made from the same substance their crystalline structure differed (Acheson, 1893, p. 287). Later, in 1905 Henri Moissan discovered natural SiC crystal inside a meteorite thus the mineralogist community named the mineral moissanite (Saddow and Agarwal, 2004). In 1907, was the year were the first Light Emitting Diode (LED) was produced by H. J. Round, when by placing contacts on a SiC crystal and applying 10V, yellow, green and orange luminescence was observed at the cathode (Brezeanu, 2005). Decades later, a renewal of interest surrounding SiC emmerged when the seeded sublimation growth invented by

Tairov and Tsvetkov (1978) made the creation of SiC wafers a reality, thus giving the material the opportunity to be studied for electronic applications. Three years later, Matsunami, Nishino and Ono (1981) showed that the creation of a single crystal of SiC on a Si substrate was feasible increasing the number and variety of possible applications even more. A huge milestone occurred in 1987 when through the use of " step controlled epitaxy", high quality epitaxy of SiC could be made at low temperature on off-axis substrates (Kuroda *et al.* , 1987). Based on this breakthrough Cree Inc. was founded in 1989, and manufactured the first commercial blue LEDs based on SiC along with the production of SiC wafers.

2. 2. 2 Crystal structure polytypes and characteristics

4. Examples of applications of CDC (Carbide derived Carbon)

The multiple nanostructures that CDC presents, makes it a strong candidate to be implemented in numerous potential applications. In their paper, Presser, Heon and Gogotsi (2011) delineate the major research fields for future applications that CDC is currently attracting. In particular, these fields are: (1) The creation of Graphene based electronic devices (2) CDC as a new electrode material for supercapacitors (3) The use of CDC in fuel cells as a gas storage (e. g. hydrogen, methane) (4) CDC application in tribological coatings (5) Pt catalyst on CDC support (6) Protein sorption using CDC . Apart from the aforementioned fields another application area under research is to use CDC for CDI (capacitive deionization) of water or for desalination. The following chapters will give an extensive view of the research done on these fields although the main focus is the .

4. 1 Graphene based electronic devices

In 2003, (Dimitrijev and Jamet) published a paper were they stated that “ Although SiC offers substantial advantages over Si, in terms of physical properties and thermal stability, it cannot compete Si devices in the areas of low cost, functional density, and moderate temperature applications. However, SiC has created its own applications niche where its unique material properties – high electric breakdown field, high thermal conductivity, and high saturated electron drift velocity – give this material significant advantages”. Since then, major manufacturers of SiC wafers such as Cree Inc., broke the 500$ barrier per wafer and made SiC accessible for researchers and the industry for optoelectronic devices (EE-Times, 1999) along with the introduction of 150 mm 4H SiC wafer in 2012 (Cree Inc., 2012). The previous breakthroughs made SiC a cheap precursor for the growth of epitaxial graphene. Grapse gia to pos to ftiaxnoume apo to prohgoumeno kefalaio. The intermediate product of Si sublimation from SiC is CDC were further process gives monolayer or multilayers of graphene. An application under research and a proposed manufacturing method, is the creation of flexible transparent electrodes for screens due to the flexibility, high electrical conductivity and strength of the material (Bae *et al.* , 2010).

Studies have shown that CDC is a powerful selective sorbent for a number of molecules due to the variety of sizes its porosity exhibits (Nikitin and Gogotsi, 2004, p. 533) and is suitable for applications such as the removal of toxins or cytokines from human blood (Yushin *et al.* , 2006). Another field of application is the removal of toxic compounds from water or the capacitive deionization (CDI) of water. Particularly, according to (Zou *et al.* , 2008) the ordered mesoporosity of CDC used as an electrode material for electrosorptive deionization is a more effective way of removing salt from water, when compared with the salt-removing capability of activated carbon. The explanation is that activated carbon materials contain randomly arranged mesopores and micropores were ordered mesoporous carbon contains predominately ordered mesopores that increase the capacity to desalinate water. Another example is the usage of CDC as catalyst supports for fuel cells (Jerome, 2005)

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