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New Boron Compound, Silicon Boride Ceramics for Capturing Thermal Neutrons (Possibility of the material application for nuclear power generation)

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As you know, boron compounds, borax ($Na_2B_4O_5(OH)_4 \cdot 8H_2O$) etc. were known thousands of years ago. As for natural boron, it has two naturally occurring and stable isotopes, boron 11 (^{11}B) and boron 10 (^{10}B). The neutron absorption ^{10}B is included about 19～20% with 80～81% ^{11}B. Boron is similar to carbon in its capability to form stable covalently bonded molecular networks. The mass difference results in a wide range of β values between the ^{11}B and ^{10}B. The ^{10}B isotope, stable with 5 neutrons is excellent at capturing thermal neutrons. For example, it is possible to decrease a thermal neutron required for the nuclear reaction of uranium 235 (^{235}U). If ^{10}B absorbs a neutron (^{1}n), it will change to $^{7}Li + ^{1}\alpha$ (α ray, like ^{4}He) with prompt γ ray from ^{11}B ^{11}B (equation 1).

$^{10}B + ^{1}n \rightarrow ^{11}B \rightarrow$ prompt γ ray (478 keV), $^{7}Li + ^{4}\alpha$ (4He) ··· (1)

If about 1% boron is added to stainless steel, it is known that a neutron shielding effect will be 3 times the boron free steel. Enriched boron or ^{10}B is used in both radiation shielding and in boron neutron capture therapy. Then, ^{10}B is used for reactivity control and in emergency shutdown systems in nuclear reactors. Furthermore, boron carbide, B_4C, is used as the charge of a nuclear fission reaction control rod material and neutron cover material for nuclear reactors. The B_4C powder of natural B composition is used as a charge of a control material of a boiling water reactor (BWR) which occupies commercial power reactors in nuclear power generation. The B_4C sintered body which adjusted ^{10}B concentration is used as a charge of a control material of the fast breeder reactor (FBR) currently developed aiming at establishment of a nuclear fuel cycle. In this study for new boron compound, silicon boride ceramics for capturing thermal neutrons, preparation and characterization of both silicon tetraboride (SiB_4) and silicon hexaboride (SiB_6) and ceramics produced by sintering were investigated in order to determine the suitability of this material for nuclear power generation. The relative density increased with increasing sintering temperature. With a sintering temperature of 1,923 K, a sintered body having a relative density of more than 99% was obtained. The Vickers hardness increased with increasing sintering temperature. The best result was a Vickers hardness of 28 GPa for the SiB_6 sintered at 1,923K for 1 h. The high temperature Vickers hardness of the SiB_6 sintered body changed from 28 to 12 GPa in the temperature range of room temperature to 1,273 K. The thermal conductivity of the SiB6 sintered body changed from 9.1 to 2.4 W/mK in the range of room temperature to 1,273 K.

Keywords: Silicon boride ceramics, Thermal neutrons, Control rod