www.elsevier.com/locate/jcrysgro

Characterization of bulk hexagonal boron nitride single Crystals grown by the metal flux technique

J.H. Edgar, T.B. Hoffman, B. Clubine, M. Currie, X.Z. Du, J.Y. Lin, H.X. Jiang

PII: S0022-0248(14)00389-3
DOI: http://dx.doi.org/10.1016/j.jcrysgro.2014.06.006
Reference: CRYS22276

To appear in: *Journal of Crystal Growth*

Received date: 1 May 2014
Accepted date: 2 June 2014

Cite this article as: J.H. Edgar, T.B. Hoffman, B. Clubine, M. Currie, X.Z. Du, J.Y. Lin, H.X. Jiang, Characterization of bulk hexagonal boron nitride single Crystals grown by the metal flux technique, *Journal of Crystal Growth,* http://dx.doi.org/10.1016/j.jcrysgro.2014.06.006

Characterization of Bulk Hexagonal Boron Nitride Single Crystals Grown by the Metal Flux Technique

J.H. Edgar, T.B. Hoffman, and B. Clubine, Kansas State University, Department of Chemical Engineering, Kansas State University, Manhattan, KS 66506, USA

M. Currie, Optical Sciences Division, Naval Research Laboratory, Washington, D.C. 20375, USA

X.Z. Du, J.Y. Lin, and H.X. Jiang, Texas Tech University, Department of Electrical and Computer Engineering, Lubbock, TX 79409, USA

Keywords
Hexagonal boron nitride, hBN, single crystals, photoluminescence, optical absorption

Abstract
The optical and physical properties of hexagonal boron nitride single crystals grown from a molten metal solution are reported. The hBN crystals were grown by precipitation from a nickel-chromium flux with a boron nitride source, by slowly cooling from 1500 °C at 2-4°C/h under a nitrogen flow at atmospheric pressure. The hBN crystals formed on the surface of the flux with an apparent crystal size up to 1 to 2 mm in diameter. Individual grains were as large as 100-200 µm across. Typically, the flakes removed from the metal were 6 to 20 µm thick. Optical absorption measurements suggest a bandgap of 5.8 eV by neglecting the binding energy of excitons in hBN. The highest energy photoluminescence peak was at 5.75 eV at room temperature. The hBN crystals typically had a pit density of 5 x 10^6 cm^{-2} after etching in a molten eutectic mixture of potassium hydroxide and sodium hydroxide. The quality of these crystals suggests they are suitable as substrates for two dimensional materials such as graphene and gallium nitride based devices.

Introduction

Single crystal hexagonal boron nitride (hBN) is the best substrate for supporting graphene, because of its similar crystal structure and lattice constants, ultrasmooth surfaces, low density of surface charge states, and wide energy band gap [1,2]. When it is encapsulated in hBN, graphene's properties are the best, including the highest reported room temperature charge carrier mobility (>140,000 $cm^2/V{\cdot}s$) [3] and ballistic transport distances of several microns [2,3].

hBN is also attractive as a substrate for other materials as well. Chan *et al* [4] reported a ten-fold increase in the electron mobility of thin MoS_2 layers on hBN compared to SiO_2 substrates. Similarly, Gehring *et al* [5] saw the surface carrier mobility of the topological insulator $BiTe_2Se$ increase by a factor of three on hBN compared to SiO_2. hBN has also been proposed as a substrate for atomically thin layers of silicon (silicene) [6] and germanium (germanene) [7]. Since hBN does not have dangling surface bonds, the epitaxial layers it supports are weakly held and can be mechanically removed, allowing their separation from the substrate, as has been demonstrated for GaN based devices by Makimoto *et al* [8] and Kobayashi *et al* [9].