MBE growth of topological insulator Bi$_2$Se$_3$ films on Si(111) substrate

Yong Seung Kim$^{1,2}$, Namrata Bansal$^2$, Eliav Edrey$^2$, Mathew Brahlek$^2$, Yoichi Horibe$^2$, Keiko Iida$^2$, Makoto Tanimura$^2$, Guo-Hong Li$^2$, Tian Feng$^2$, Hang-Dong Lee$^2$, Torgny Gustafsson$^2$, Eva Andrei$^2$, Sang-Wook Cheong$^2$, Seongshik Oh$^2$

$^1$Sejong University, $^2$Rutgers University

We will report atomically sharp epitaxial growth of Bi$_2$Se$_3$ three-dimensional topological insulator films on Si(111) substrate with molecular beam epitaxy (MBE). It was achieved by employing two step growth temperatures to prevent any formation of second phase, like as SiSe$_2$ clusters, between Bi$_2$Se$_3$ and Si substrate at the early stage of growth. The growth rate was determined completely by Bi flux and the Bi:Se flux ratio was kept $\sim$1:15. The second-phase-free atomically sharp interface was verified by RHEED, TEM and XRD. Based on the RHEED analysis, the lattice constant of Bi$_2$Se$_3$ relaxed to its bulk value during the first quintuple layer implying the absence of strain from the substrate. Single-crystalline XRD peaks of Bi$_2$Se$_3$ were observed in films as thin as 4 QL. TEM shows full epitaxial structure of Bi$_2$Se$_3$ film down to the first quintuple layer without any second phases. This growth method was used to grow high quality epitaxial Bi$_2$Se$_3$ films from 3 QL to 3600 QL. The magneto-transport properties of these thin films show a robust 2D surface state which is thickness independent.

**Keywords:** Topological Insulator, Bi$_2$Se$_3$, MBE