Optical and transport properties of semiconductor nanostructures and 2D van der Waals heterostructures under high magnetic fields

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We proposed to study optical proproperties of semiconductor quantum structures, transport and tunneling properties of two-dimensional layered materials during my guest faculty period at the IMR. We obtained significant optical transitions from $MAPbX_3$ (X=Cl, Br, I) under high magnetic fields. Unlike the optical measurements, we failed to observe transport and tunneling characteristics from graphene multilayers. This may due to the aging effect of the sample.

My term as a guest professor at the IMR – Tohoku University was May 1 2017 to July 31, 2017. The host professor was Prof. H. Nojiri. During that period, we try to investigate the optical properties of semiconductor nanostructures, and the transport and tunneling properties of two-dimensional (2D) layered materials under high magnetic fields. We did obtain anomalous photoluminescence (PL) transitions from methyl-ammonium lead halide ($MAPbX_3$ (X=Cl, Br, I)), which is known as hybrid organic inorganic perovskite crystals. MAPbX3 families are known to be used as next generation solar cells and LEDs. Therefore, tremendous research reports are under coming last few years. We obtained peculiar optical transitions from a $MAPbI_3$ crystal under high magnetic fields, which is a square root B dependency of peak transition energy. This is due may to the variation of the effective g factor in the presence of magnetic field. The conduction band structure in such perovskite materials has SOC band, which is the band minimum at the R point. A strong spin-orbit interaction can change effective g factor in magnetic fields. Consequently, the square root B dependency of the transition energy can possibly be occurred due to the strong spin-orbit interaction in the conduction band.

The material used for this study receives tremendous attention all over the world due to its potential application on the photovoltaic devices. The efficiency of the solar cell device by using this material already approaches to the silicon based solar cell devices, which was achieved only within last five years. There are numerous unknown carrier dynamics occurred in this material. The magneto-optical investigations on this material can be a valuable work to find such unknown carrier dynamics in this materials, which will guide to increase the solar efficiency for future photovoltaic device applications.

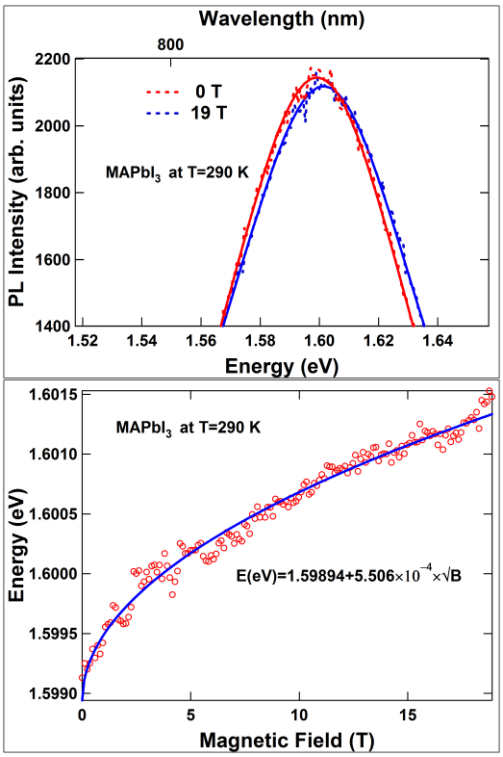

Fig.1 (upper) PL spectra at 0 and 19 T. The peak at 19 T shows blue shift. (lower) Peak transition energy vs magnetic field. Circles and solid line indicate experimental and fitted data, respectively. The experimental data follows a square root B fitting curve.

We tried to investigate tunneling properties of Au-h-BN-Graphene structure under magnetic fields. Figure 2 inset shows the

schematic diagram of the sample used for this study.

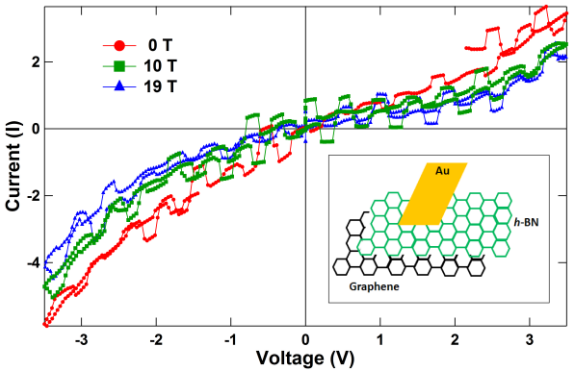

Fig. 2 I-V characteristics of Au - *h*-BN - Graphene tunnel structure (inset). Red, green and blue colors are I-V curves at 0, 10 and 19 T.

As seen in Fig. 2, red, green and blue markers are the I-V curves under magnetic fields at 0, 10 and 19 T, respectively. In this figure, we do not clearly distinguish I-V curves between 0 and 10 T. There is small change at 19 T. We realized that the sample can be contaminated by oxygen, water and/or O-H when it is exposed to the air, which can deteriorate the I-V characteristics. The sample used for this study was exposed at least a month in the air. Therefore, the I-V characteristics in this study cannot be reliable. We planned to redo the experiments with fresh samples.

In summary, we have measured optical transitions of $MAPbX_3$ (X=Cl, Br and I) hybrid organic-inorganic perovskite crystals and magneto-tunneling properties of an Au-*h*-BN-graphene tunnel device. We obtained anomalous optical transition from a MAPbI3 single crystal under high magnetic fields. This is due may to the strong spin-orbit coupling, which modifies the effective g factor of the conduction and electrons in the presence of magnetic field. For tunneling properties of Au-h-BN-graphene device, due to the contamination by the air exposure for a long time, the device characteristics are vague. We planned to

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