2022 年　04 月　29 日

2021 年度若手研究者共同研究プロジェクト実施報告書

法政大学総長　殿

以下のとおり研究実施報告書を提出します。

<table>
<tr><td rowspan="7">基本情報</td><td>研究課題名：Effects of defect formation by low energy Ar^+ ion beam irradiation in monolayer MoS_2</td></tr>
<tr><td>研究代表者　氏名：ZHAO Yangzhou</td></tr>
<tr><td>（在籍者）研究科・専攻・学年：理工学研究科　応用化学専攻　博士後期課程　3 年
（修了者）所属・職種：</td></tr>
<tr><td>指導教員（所属・職・氏名）：Kazuyuki Takai
（※在籍者のみ記入）</td></tr>
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（※指導教員と同人の場合は記入不要）</td></tr>
<tr><td>その他　研究分担者：</td></tr>
<tr><td>研究期間：　　２０２１年度　～　２０２１年度（※研究修了年度を記載）</td></tr>
<tr><td>年間の研究実施概要</td><td>※研究計画の進捗状況を中心に今年度の研究実施状況を記載してください。
Optical microscope with an adapted digital camera purchased by the research budget is used to evaluate the number of layers of MoS_2 by checking the brightness contrast between the sample and the SiO_2 / Si substrate in red-color wavelength channel, and then compared with reference to evaluate the layer count.
 
After monolayer sample is confirmed, electrodes will be attached by Electron Beam lithography.
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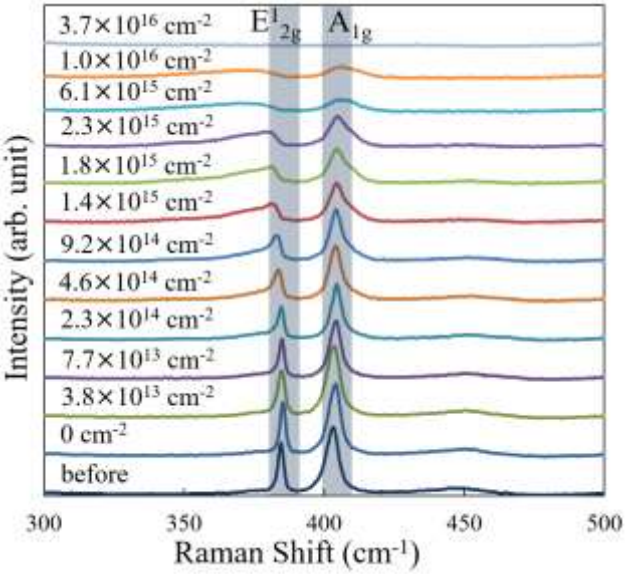
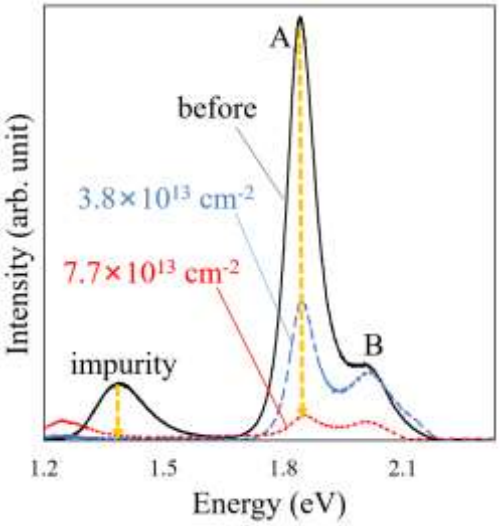
年間の研究実施概要

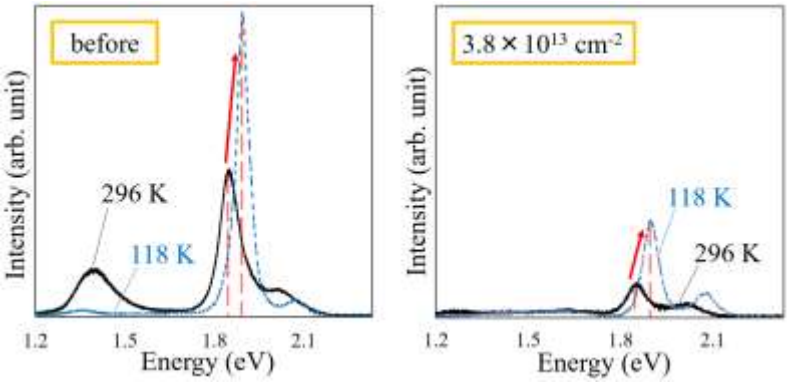
Raman spectra for monolayer MoS_2 are measured after irradiation with various dosage. The dosage of ion beam gun is fixed by adjust the Argon gas pressure, the filament current and the emission voltage, and the dosage has bees accurately measured by means of the detections for irradiation area and beam current.



At low irradiation dose condition, a new peak at around 450 wavenumber appears, indicating that S vacancies are introduced. After the dosage of 1.4×10^{15} cm^{-2}, both E_{2g} around 380 cm^{-1} and A_{1g} around 410 cm^{-1} peaks become wider, also redshift in the E_{2g} peak appears for Mo vacancies introduction. After the dosage of 6.1×10^{15} cm^{-2}, significant redshift in the E_{2g} peak and diminishing in the A_{1g} peak indicates that MoS_6 vacancies are introduced.

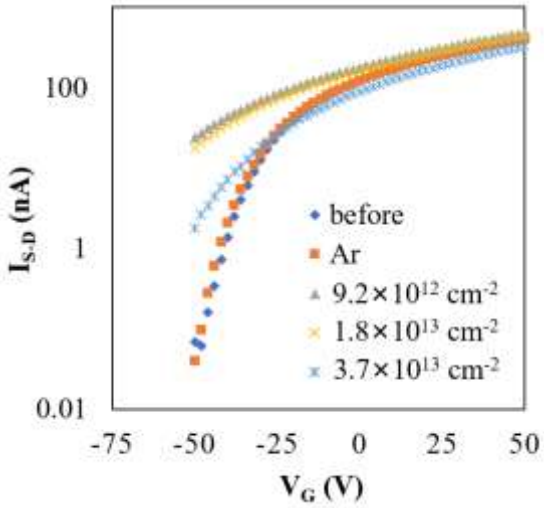


Photoluminescence (PL) for monolayer MoS_2 is also measured after irradiation. It was found that PL is much more sensitive under the low irradiation dose. After the ion beam irradiation, A peak around 1.85 eV decreases and impurity peak D around 1.3 eV disappears, which indicate the non-radiative relaxation of electrons transitioning to defect level appears.



We also find A peak upshift and its intensity increases in low temperature. It is

considered as band gap increasing due to thermal shrinkage of the lattice, and the electron transition to defect levels by phonons has been suppressed.



The conductivity of monolayer MoS_2 FET is measured at various irradiation dosage. at first, only the Argon gas introduction does not affect the electrical transport properties. The threshold voltage for MoS_2-FET shifts to the negative side after Ar^+ beam irradiation, with minor mobility decrease. However, With the increasing of irradiation dosage, positive shift appears upon the irradiation dose, indicating hole doping of MoS_2 caused by Ar^+ ion irradiation appears. We consider it as charge transfer from terminating oxygen atoms of defects originating from the residue oxygen gas in the measurement vacuum chamber.

By means of these tests for MoS_2 after Ar^+ ion irradiation, it is found that S vacancies exist as fabricated and be introduced at low irradiation dosage. Also, only S vacancies are introduced in PL and FET test. Non-radiative relaxation paths are also introduced by defect states in the lower energy region which causes hole carriers in the valence band. Thus, the emission from deep impurity levels in the gap becomes suppressed as well as the main emission from the conduction band minimum at the K point. The conductivity measurement points out the dosage dependence for transport properties, which is a valuable reference for further research.

研究業績

成果発表（学会・論文・研究会等）

学会・論文・研究会等の別	タイトル	発行または発表年月
International Conference on the Science and Application of Nanotubes and Low-Dimensional Materials (NT21)	Effects of defect formation by low energy Ar+ ion beam irradiation in monolayer MoS2	Jun. 09, 2021
The 40th Symposium on Materials Science and Engineering Research Center of Ion Beam Technology	Introducing lattice vacancies as adsorption sites in monolayer MoS2	Dec. 08, 2021
The 62nd Fullerenes-Nanotubes-Graphene General Symposium (FNTG 62)	Effects of lattice vacancies introduced by ion-beam irradiation in monolayer MoS2	Mar. 03, 2022

その他（アピールすることがあればご記入ください。）

Yangzhou Zhao, Hiroki Yokota, Haruna Ichikawa, Yasushi Ishiguro, Kazuyuki Takai. Effects of defect formation in monolayer MoS2 by low energy Ar+ ion beam irradiation. (in preparation)