Unveiling Mechanisms of Photocurrent Induced by Orbital Angular Momentum of Light in MoS_2 Transistors

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Abstract

The presence of orbital angular momentum (OAM) in light introduces a selection principle rooted in momentum conservation, thereby allowing transitions that were previously prohibited. The interaction of OAM-carrying light with Transition Metal Dichalcogenides (TMD) materials enables the selective excitation of excitonic transitions. In this research, we explore the optical and electrical properties of a field-effect transistor constructed from molybdenum disulfide (MoS_2) using OAM of light as the excitation source. Our observations reveal a decrease in the rate of exciton luminescence, but a simultaneous enhancement in the device photoconductance as the OAM content of the incident light is intensified. These results suggest a reciprocal relationship between the concentration of exciton-bound states and free carriers. We infer that the additional momentum introduced by the OAM of light impedes the optical emission rate and promotes the dissociation of excitons, consequently amplifying the photoconductance of the device. Our study offers insight into the potential mechanism for enhancing photocurrent using OAM-carrying light.

Summary

Laguerre-Gaussian (LG) beams exhibit an electric field amplitude distribution closely resembling the Gaussian distribution in the transverse plane. The presence of a non-zero quantized azimuthal index ℓ introduces a periodic phase difference. This phase difference gives rise to a helical wavefront in the propagating light, often referred to as "twisted light," imparting quantized orbital angular momentum (OAM) with a magnitude of $\ell\hbar$.

Our experimental findings reveal a progressive increase in the photocurrent of a MoS_2 Field-Effect Transistor (FET) with the growing intensity of the OAM-carrying excitation source. Conversely, we observed a decrease in exciton photoluminescence (PL) from the MoS_2 channel as the OAM increased, which is depicted in Figure 1a and 1b.

In our observations, the OAM of light extends the exciton radiative lifetime and induces a blue shift in the PL spectroscopy. Guided by the principle of momentum conservation, we infer that excitonic transitions permit the inclusion of OAM in the center of mass (CoM) momentum of excitons, potentially slowing down the optical emission rate. When considering the Rydberg exciton states, it becomes evident that the transition of OAM confines the excited Rydberg exciton with the same total angular momentum quantum number ℓ, stemming from the quantized OAM of light. This confinement implies that the Rydberg exciton will be excited to states with quantum numbers n greater than one, leading to a blue shift in the optical emission from Rydberg excitons in the PL results.

In summary, our findings suggest that the OAM of light hinders the exciton radiative emission rate while enhancing its dissociation rate. This increases the likelihood of excitons transforming into free carriers, which can be collected by an applied bias voltage, ultimately improving the photoconductance of the MoS_2 FET device.

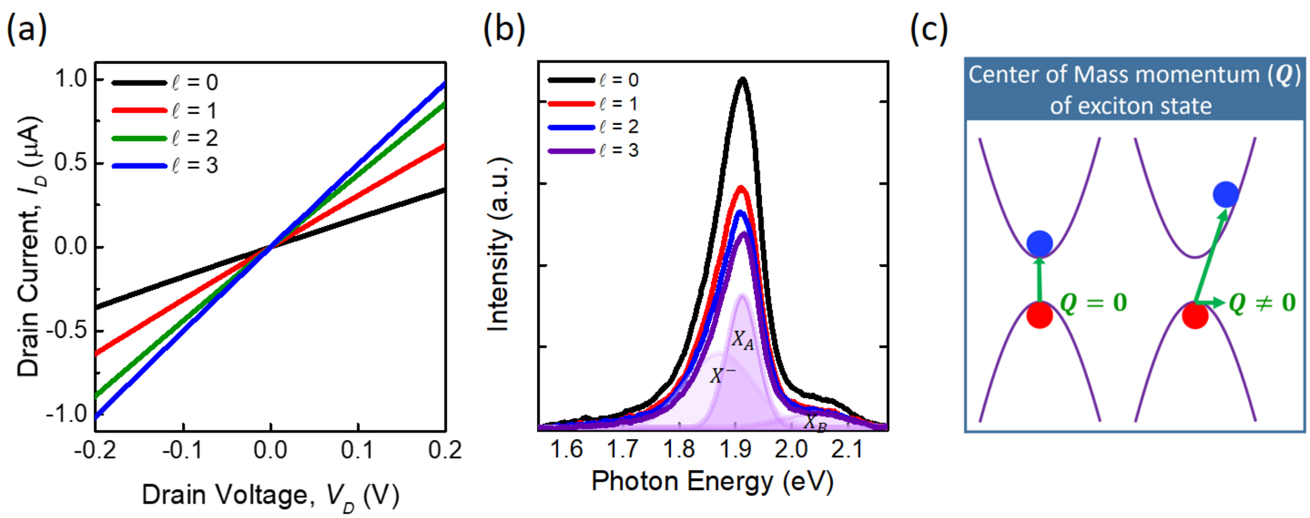

Figure 1. (a) The $I_D - V_D$ characteristic of the device illuminated by the OAM of light. (b) The photoluminescence result by the OAM with the magnitude from 0 to 3. (c) Sketch of the center of mass momentum transfer from OAM-carrying light.

Reference

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