Photoluminescence spectroscopy of metal nanoantennas coupled to the atomically thin semiconductor WS_2

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Application Note

Introduction

Atomically-thin transition metal dichalcogenides, such as MoS_2, $MoSe_2$, WS_2 and WSe_2 are an emerging class of two-dimensional materials beyond graphene. They are of special interest for optical and opto-electronic devices, since they possess an optical band gap in the visible or infrared regime.

In our research group, we investigate the fundamental physical properties of these materials [1] and study how the light-matter interaction of the atomically-thin material can be enhanced by coupling to metal nanostructures [2]. We use spatially-resolved photoluminescence (PL) and dark-field scattering spectroscopy to investigate a hybrid system consisting of an atomically-thin semiconductor and a plasmonic nanoantenna.

Setup

In order to obtain photoluminescence maps as well as photoluminescence spectra we use a homebuilt wide-field optical microscope (Figure 1). Photoluminescence is excited by a continuous wave 588 nm solid-state laser. Sideband emission of the laser is suppressed using a bandpass filter. The laser is focused into the back focal plane of the objective lense (100x/NA=0.9) using a system of a convex and concave lense. In that way, a homogenous illumination of the sample is achieved. The photoluminescence is collected with the same objective lense and the detection path is separated from the excitation path via a beamsplitter (50:50). Reflected laser light is blocked with a longpass filter. The photoluminescence is imaged through a spectrograph (Andor Shamrock SR-303i-B) onto a sCMOS camera (Andor Neo-5.5-CL3). In order to illuminate a large area of the sCMOS chip, the spectrograph entrance has a wide aperture slit option. The grating turret of the spectrograph is equipped with a silver mirror, 150 lines/mm and 300 lines/mm gratings. Spatially resolved photoluminescence spectra can be obtained by selecting the sample position by the slit (x-direction) and binning over the desired amount of pixels (y-direction). For polarization analysis a polarizer can be inserted into the excitation and/or detection path.

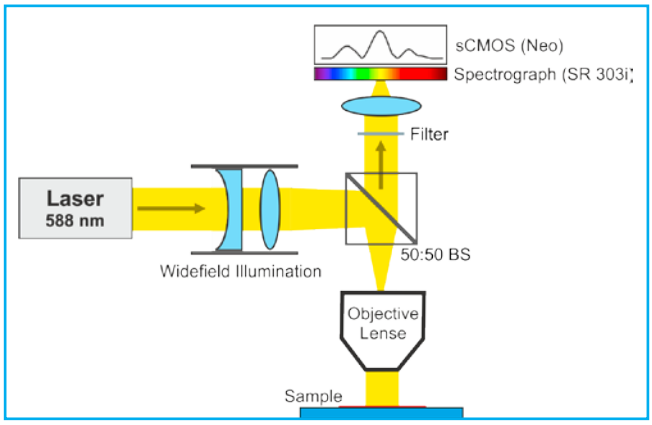

Figure 1. Schematic drawing of the wide-field microscope used for spatially resolved photoluminescence spectroscopy.

Photoluminescence Spectroscopy of a metal nanoantenna-monolayer hybrid

The investigated hybrid system consisting of an atomically thin WS_2 layer and a metal nanoantenna is schematically drawn in Figure 2. In the electron micrograph the triangular WS_2 monolayers appear dark and the gold nanorods on top are bright. Four rods are marked by dashed white circles.
Photoluminescence intensity maps are recorderd for excitation with circularly polarized light using the experimental setup described above. At position of the gold nanoantennas the photoluminescence is strongly enhanced. A normalized photoluminescence spectrum of a hybrid nanoantenna-monolayer system as well as the bare monolayer WS_2 is shown in Figure 3.
The plasmonic resonance of the nanoantenna clearly modifies the spectral shape of the photoluminescence. We observe a dipolar radiation pattern when varying the excitation polarization with respect to the antenna axis (inset in Figure 3) and find strongest enhancement when the polarization is matched with the antenna axis. The spectral modification as well as the prominent polarization behavior are caused by the enhanced emission rate due to the plasmon resonance of the nanoantenna.

Additional studies performed with this microscope include the analysis of emission polarization as well as scattering spectroscopy of various hybrid systems.

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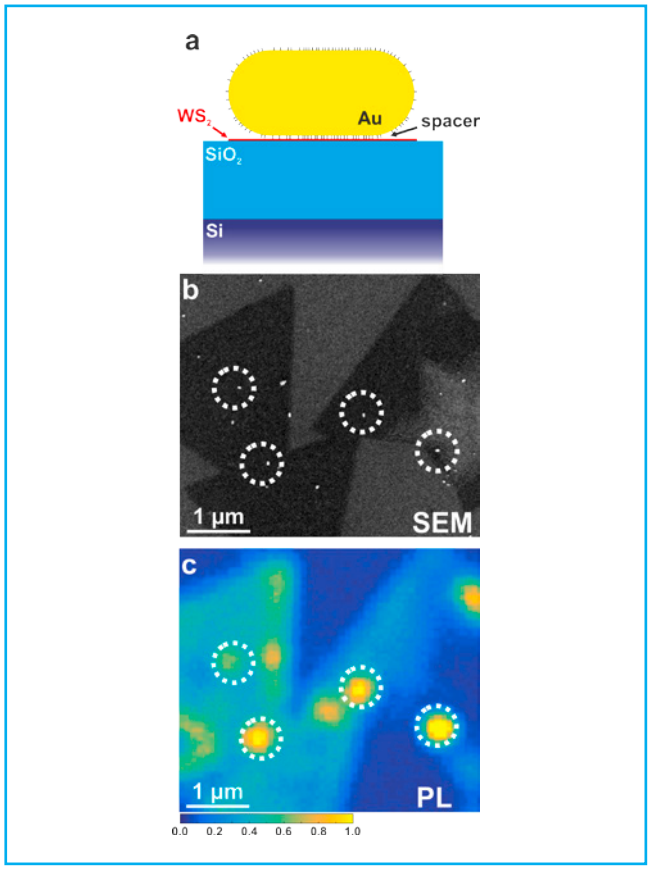

Figure 2. (a) Schematic drawing of the sample. (b) Electron micrograph of monolayer WS_2 (dark triangles) with gold nanorods on top (bright rods). (c) Normalized photoluminescence intensity map of the region shown in (b). Photoluminescence enhancement is found at position of the nanorods.

Application Note

Conclusion

The widefield microscope equipped with a Shamrock 303i spectrograph and an Andor Neo sCMOS camera has enabled us to investigate the optical properties of a hybrid nanosystem consisting of a metal nanoantenna and a monolayer of WS_2 [2].

Literature

(1) Tonndorf, P.; Schmidt, R.; Böttger, P.; Zhang, X.; Börner, J.; Liebig, A.; Albrecht, M.; Kloc, C.; Gordan, O.; Zahn, D. R.; others. Opt. Express 2013, 21 (4), 4908–4916.

(2) Kern, J.; Trügler, A.; Niehues, I.; Ewering, J.; Schmidt, R.; Schneider, R.; Najmaei, S.; George, A.; Zhang, J.; Lou, J.; Hohenester, U.; Michaelis de Vasconcellos, S.; Bratschitsch, R. ACS Photonics 2015, 2 (9), 1260–1265.

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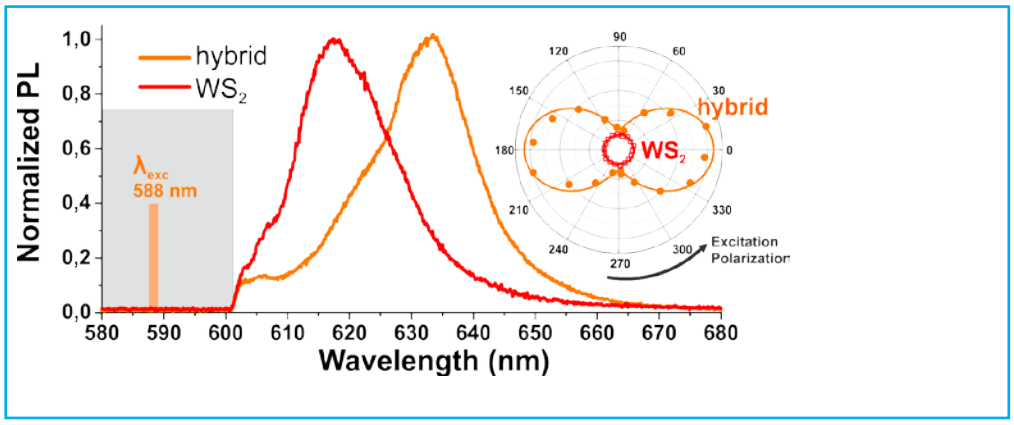

Figure 3. Photoluminescence spectrum and angular dependence of the photoluminescence intensity depending on excitation polarization for the hybrid system as well as the bare WS_2 monolayer. Photoluminescence enhancement is strongest when the polarization is matched to the long axis of the antenna.