Electronic Supplementary Material (ESI) for Nanoscale.

Supplementary Materials for

Silicon nitride waveguides with directly grown WS_2 for efficient second-harmonic generation

Ning Liu,‡[a] Xi Yang,‡[a], Zhihong Zhu,[a] Feng Chen,[b] Yangbo Zhou,[b] Jipeng Xu,[a] and Ken Liu *[a]

[a]*College of Advanced Interdisciplinary Studies & Hunan Provincial Key Laboratory of Novel Nano-Optoelectronic Information Materials and Devices, National University of Defense Technology, Changsha 410073, P. R. China. E-mail: liukener@163.com*
[b]*School of Materials Science and Engineering, Nanchang University, Nanchang 330031, P. R. China.*
‡These authors contributed equally to this work.

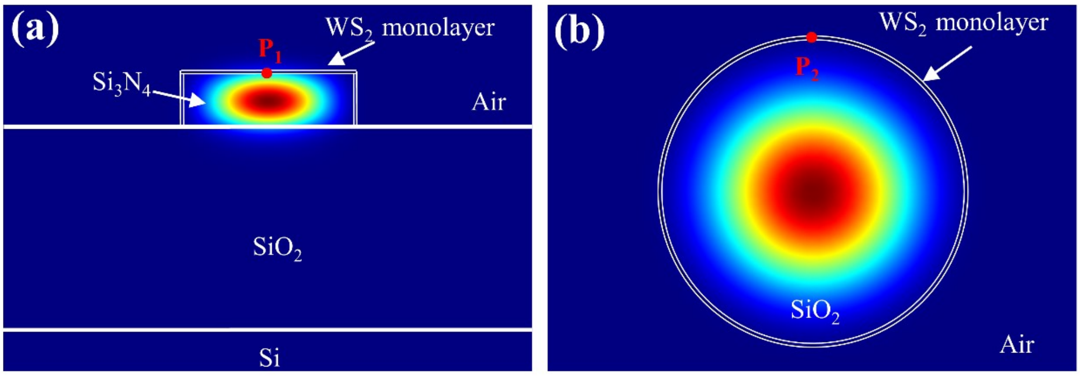

Fig. S1. Fundamental TE mode distribution of Si_3N_4 waveguide and silica fiber covered by a monolayer WS_2. (a) Fundamental TE mode distribution of the TE mode in the Si_3N_4/WS_2 hybrid waveguide structure. The width and the height of the Si_3N_4 waveguide is 2.0 μm and 0.6 μm, respectively. The thickness of the WS_2 monolayer is set to be 0.65 nm. (b) Fundamental TE mode distribution of a microfiber covered by a monolayer WS_2. The diameter of the core is set to be 4 μm.

We use the simulation software "*COMSOL*". The wavelength is set to be 1,550 nm and the refractive index n of monolayer WS_2 is set to be 4.5.[1] Fig. 1 shows the fundamental TE mode distribution of the Si_3N_4 waveguide covered by a monolayer WS_2 on the top and both sides and a 4 μm-diameter microfiber also covered by a monolayer WS_2. The confinement factor of the monolayer WS_2 can be expressed as:[2]

$$\Gamma = \frac{\int_{ws_2} \varepsilon_{ws_2} |E_{\parallel}|^2 dV}{\int_V \varepsilon |E|^2 dV}$$

Where ε is the dielectric constant, and $E_{\parallel}$ is the electric field in the analyzing plane. $\Gamma \approx 0.17\%$ for the Si_3N_4/WS_2 hybrid waveguide and $\Gamma \approx 0.065\%$ for the SiO_2/WS_2 microfiber. The confinement factor in the hybrid waveguide is 162% higher than that in the microfiber.

For the same pump power, we calculated the magnitude of electric field |E| in the monolayer WS_2 for the P_1 point in Fig. 1(a) and the P_2 point in Fig. 1(b). The results show that the value of |E| at P_1 is about 27 times as much as that of the point P_2, which means that the second-order nonlinearity of the Si_3N_4/WS_2 hybrid waveguide is much higher than that of the microfiber covered by a monolayer WS_2, since the SHG effect is proportional to $|E|^2$.

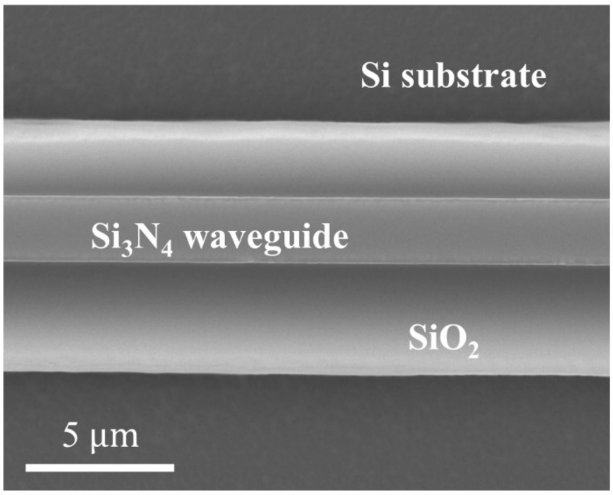

Fig. S2. SEM image of the Si_3N_4 waveguide with SiO_2 etched at both sides before the subsequent WS_2 growth.

References

1 H. L. Liu, C. C. Shen, S. H. Su, C. L. Hsu, M. Y. Li and L. J. Li, *Appl. Phys. Lett.*, 2014, **105**, 4.

2 Y. Ye, Z. J. Wong, X. F. Lu, X. J. Ni, H. Y. Zhu, X. H. Chen, Y. Wang and X. Zhang, *Nat. Photonics*, 2015, **9**, 733-737.