Confined Surface Waves in Layered Dielectric Materials

A. M. Dubrovkin[1], B. Qiang[1], N. I. Zheludev[1,2], Q. J. Wang[1,3]

1. *Centre for Disruptive Photonic Technologies, TPI, SPMS, Nanyang Technological University, 637371 Singapore*
2. *Optoelectronics Research Centre and Centre for Photonic Metamaterials, University of Southampton, SO17 1BJ, UK*
3. *OPTIMUS, Centre for OptoElectronics and Biophotonics, School of Electrical and Electronic Engineering, Nanyang Technological University, 639798 Singapore*

Abstract: We demonstrate deep subwavelength confinement of surface phonon-polaritons in silicon carbide by capping the crystal with nanometric layers of MoS_2. Near-field nano-imaging shows 85 time surface wave confinement in comparison with free-space wavelength of 11.15 micrometers.

Highly confined surface polaritons [1-3] attract increasing attention as a promising platform for nanoscale opto-electronic devices enabling strong light-mater interactions. Recently, a new approach for confining surface phonon-polaritons (SPhPs) in bulk polar crystals by ultrathin capping layer [3] has been experimentally demonstrated in quartz/GST system. However, the ultimate performance of the device was limited by the film quality on few-nm thickness scale, and would also require a stronger polar crystal. In this work, we meet these requirements by placing nanometric layers of 2-dimensional materials (2DM) on bulk silicon carbide substrate. Scattering-type scanning near-field optical microscopy (s-SNOM) revealed deeply subwavelength confinement of SPhPs in SiC/2DM interface at mid-IR frequencies, which sharply depends both on the 2DM thickness and the excitation wavelength.

To experimentally excite SPhPs we use mid-IR radiation of CO_2-gas laser at frequencies between 930 and 897 cm^{-1}. An example of phonon-polariton interferometry pattern near the edge of 6-nm MoS_2-on-SiC flake is shown in Fig. 1. The estimated SPhP confinement factor, k_{SPhP}/k_0 reaches value of 85. SPhPs dispersion was theoretically calculated, based on analysis of imaginary part of the reflection coefficients using the transfer matrix method together with direct solving of the analytical equation for the 3-layer interface system. We experimentally perform a systematic study of thickness and spectral dependency of the confinement factor, and fit the data with theoretically calculated values. Furthermore we assess a potential application of several 2DM for SPhP confinement on the SiC interface.

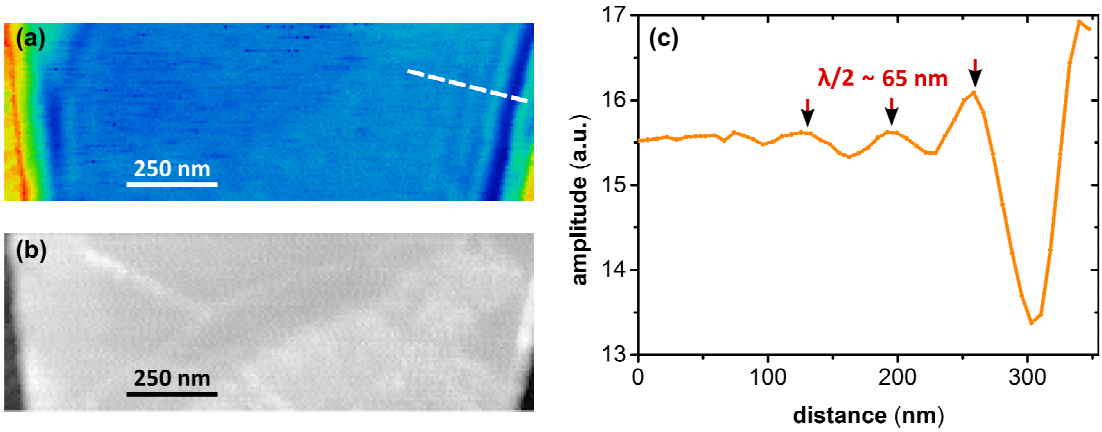

Fig. 1 (a) Near-field amplitude image (4th harmonic) recorded at ω = 897 cm^{-1}; (b) Topography of ~6 nm MoS_2 flake on the SiC substrate; (c) Cross-section along the white dotted line in the image (a).

Approach discussed in our work enables realization of ultimate light-matter interaction on the interface of bulk polar crystals and nanometric capping layer down to the fundamental atomic limit, opening a new avenue on the surface phonon-polaritons confinement at nanoscale.

References

[1] Z. Fei, A. S. Rodin, G. O. Andreev, W. Bao, A. S. McLeod, M. Wagner, L. M. Zhang, Z. Zhao, M. Thiemens, G. Dominguez, M. M. Fogler, A. H. Castro Neto, C. N. Lau, F. Keilmann, D. N. Basov, "Gate-Tuning of Graphene Plasmons Revealed by Infrared Nano-Imaging," Nature **487**, 82 (2012).

[2] S. Dai, Z. Fei, Q. Ma, A. S. Rodin, M. Wagner, A. S. McLeod, M. K. Liu, W. Gannett, W. Regan, K. Watanabe, T. Taniguchi, M. Thiemens, G. Dominguez, A. H. Castro Neto, A. Zettl, F. Keilmann, P. Jarillo-Herrero, M. M. Fogler, D. N. Basov, "Tunable Phonon Polaritons in Atomically Thin van der Waals Crystals of Boron Nitride," Science **343**, 1125 (2014).

[3] P. Li, X. Yang, T. W. W. Maß, J. Hanss, M. Lewin, A.-K. U. Michel, M. Wuttig, T. Taubner, "Reversible Optical Switching of Highly Confined Phonon–Polaritons with an Ultrathin Phase-Change Material," Nat. Materials **15**, 870 (2016).