



# Giant Gap-Plasmon Tip-Enhanced Raman Scattering of MoS<sub>2</sub> Monolayers on Au Nanocluster Arrays

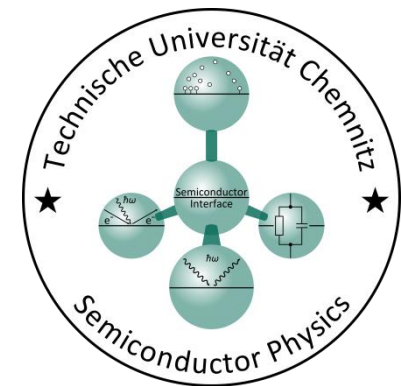
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V.M. Dzhagan<sup>1,4</sup>, and D.R.T. Zahn<sup>1</sup>

<sup>1</sup>Semiconductor Physics, Chemnitz University of Technology, D-09107, Chemnitz, Germany

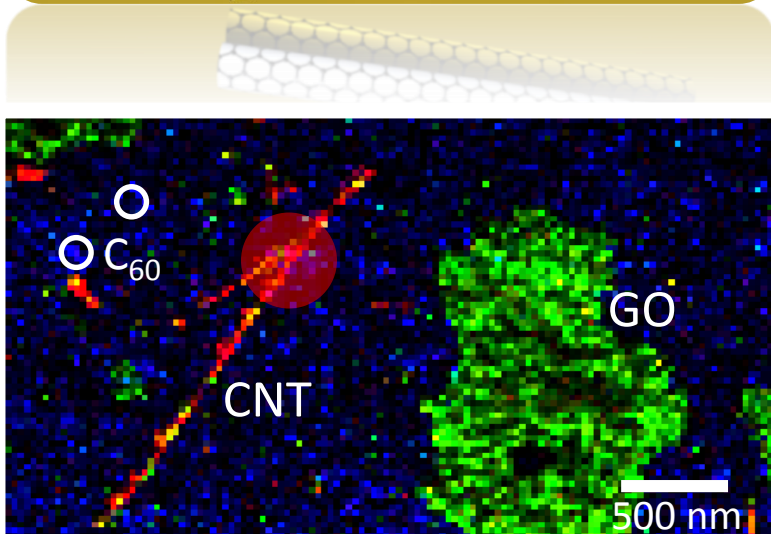
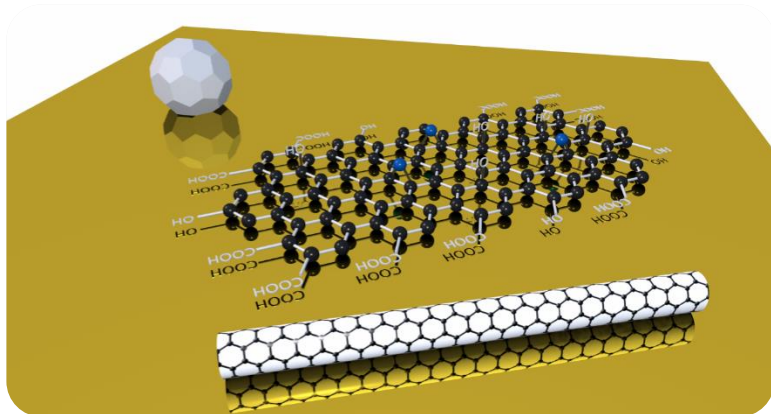
<sup>2</sup>Novosibirsk State University, Pirogov 2, 630090, Novosibirsk, Russia

<sup>3</sup>Rzhanov Institute of Semiconductor Physics RAS, Lavrentiev Ave. 13, 630090, Novosibirsk, Russia

<sup>4</sup>V. Lashkaryov Institute of Semiconductors Physics, Nat. Acad. of Sci. of Ukraine, 03028, Kyiv, Ukraine

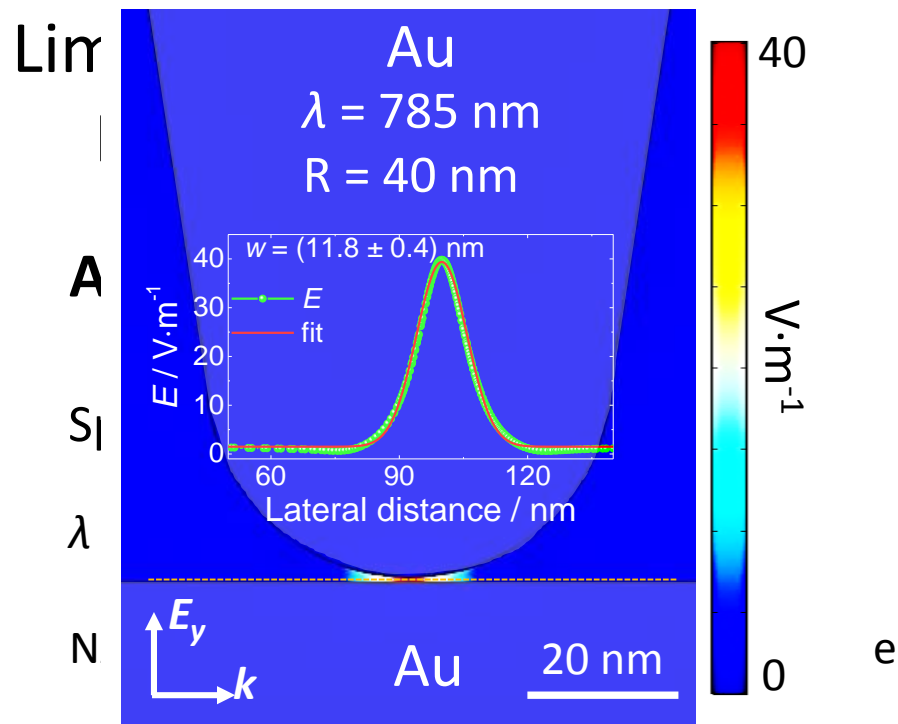


## Tip-Enhanced Raman Spectroscopy

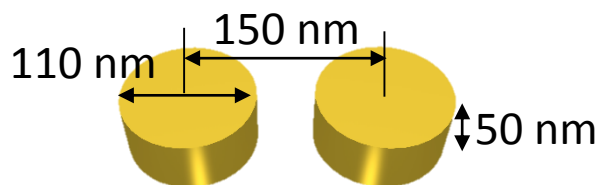
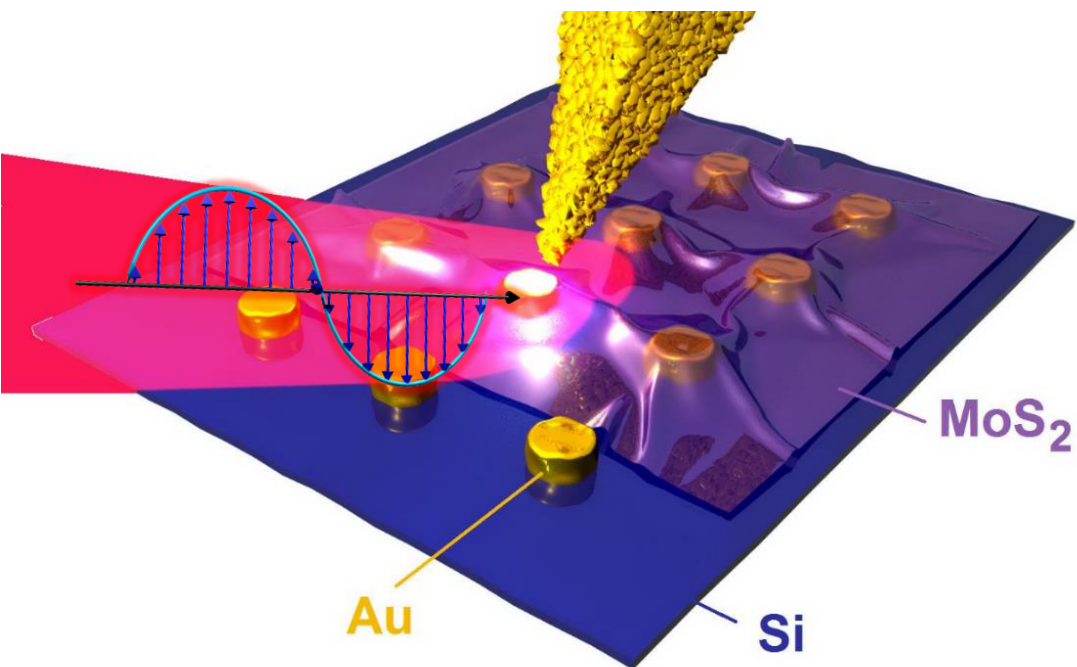


Sheremet *et al.*; *Carbon* 96 588 2016

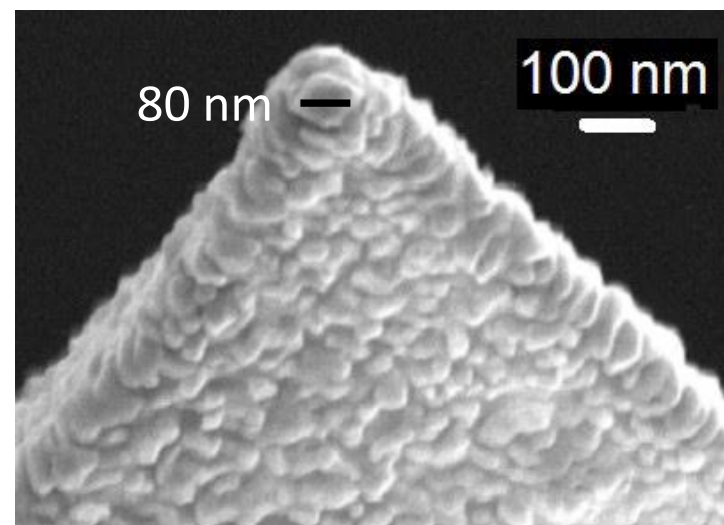
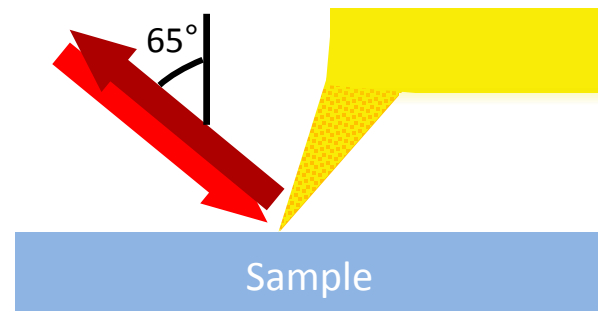
## Electrical field confinement



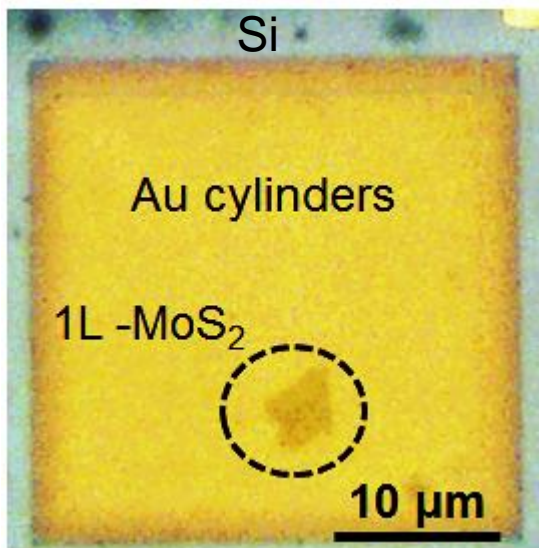
COMSOL simulation



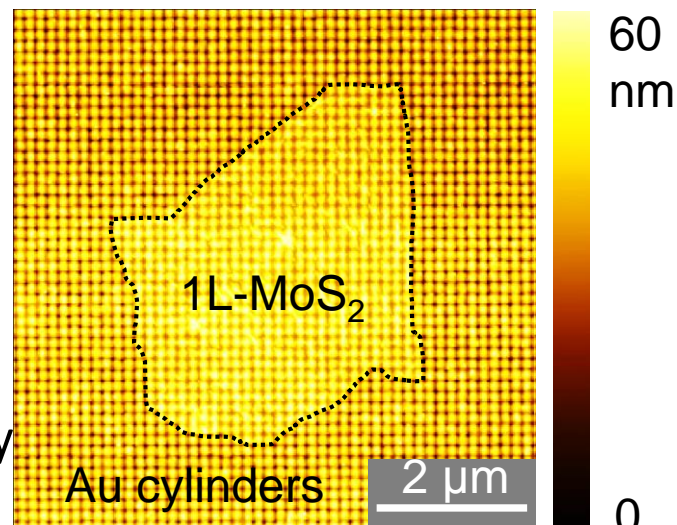
$\lambda = 785 \text{ nm}$ ; 100x, 0.7 NA, 3 mW



SEM image

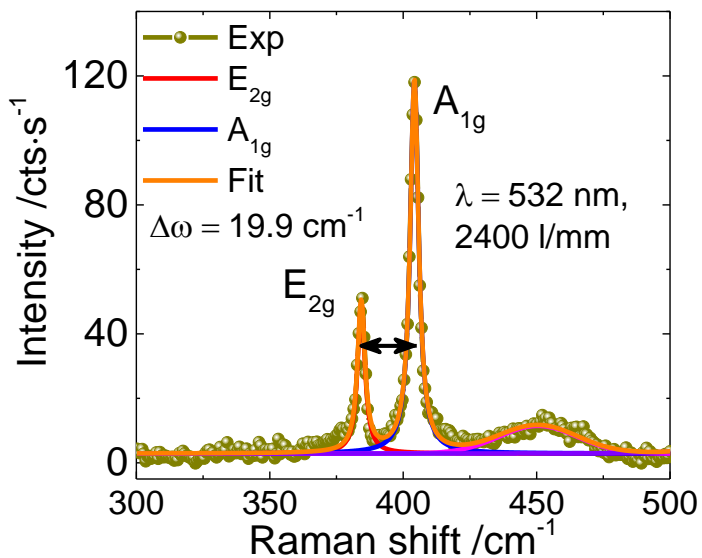


Optical image

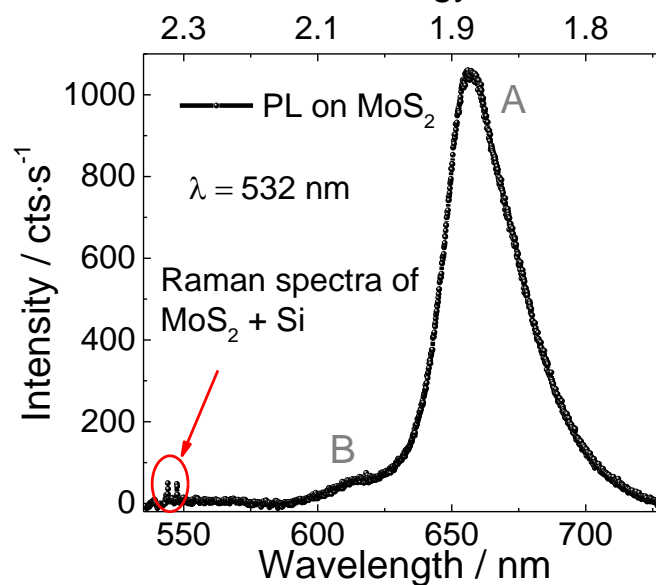


AFM topography

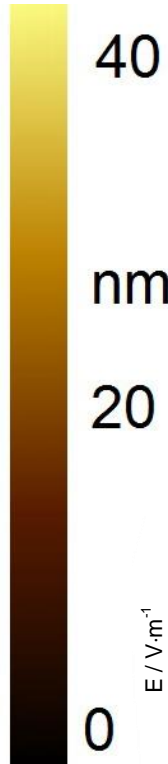
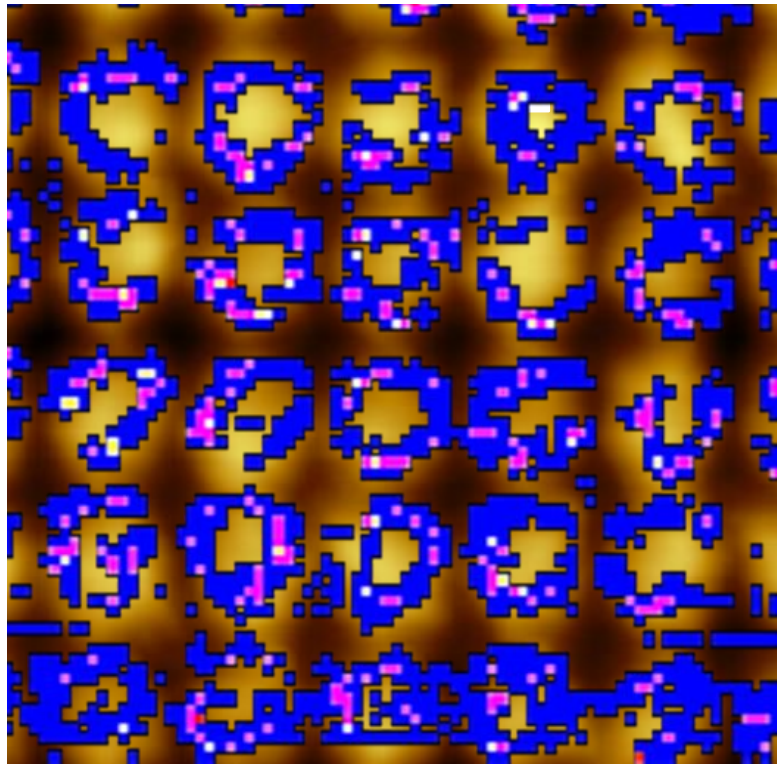
Micro-Raman spectra



Photon energy / eV

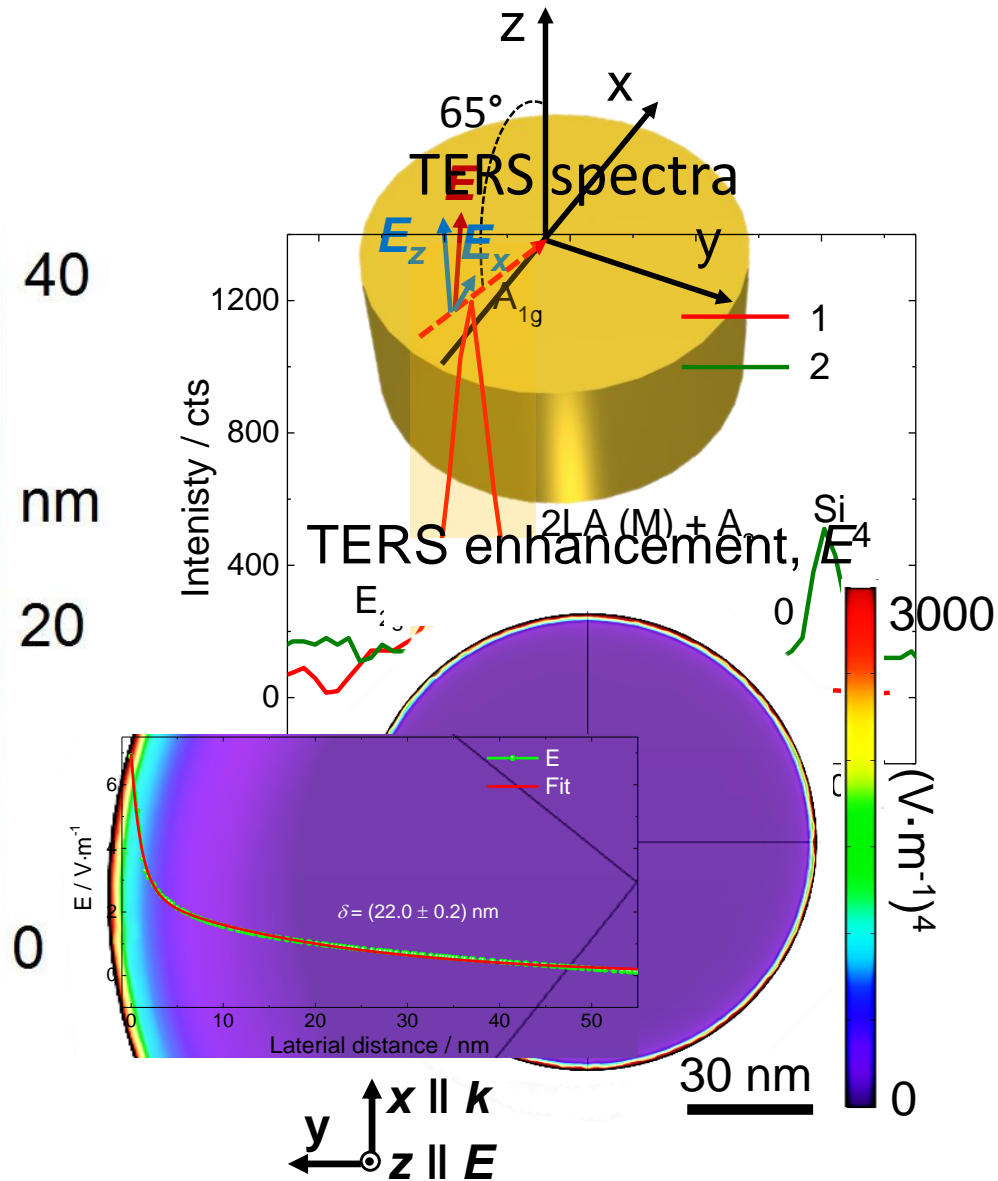


TERS map @ (390 – 430) cm<sup>-1</sup>

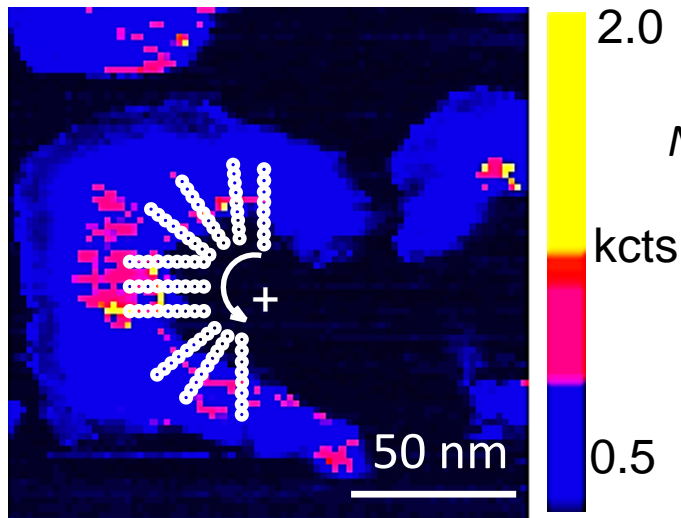


785 nm, 600 l/mm, 3 mW approx

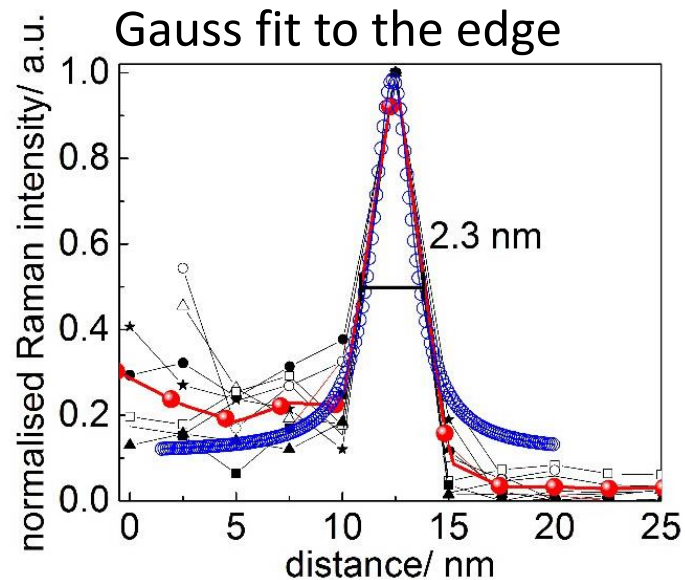
Milekhin *et al.*, *Nanoscale*, 10 2755 2018



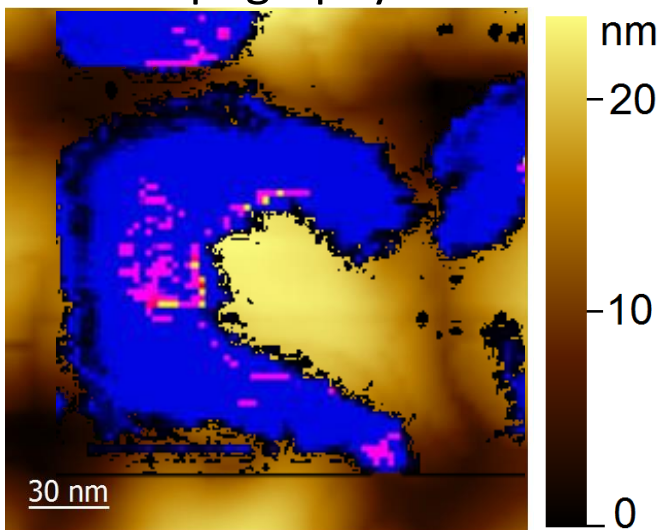
TERS map @ (390 – 430) cm<sup>-1</sup>



Milekhin *et al.*,  
*Nanoscale*, 10 2755 **2018**



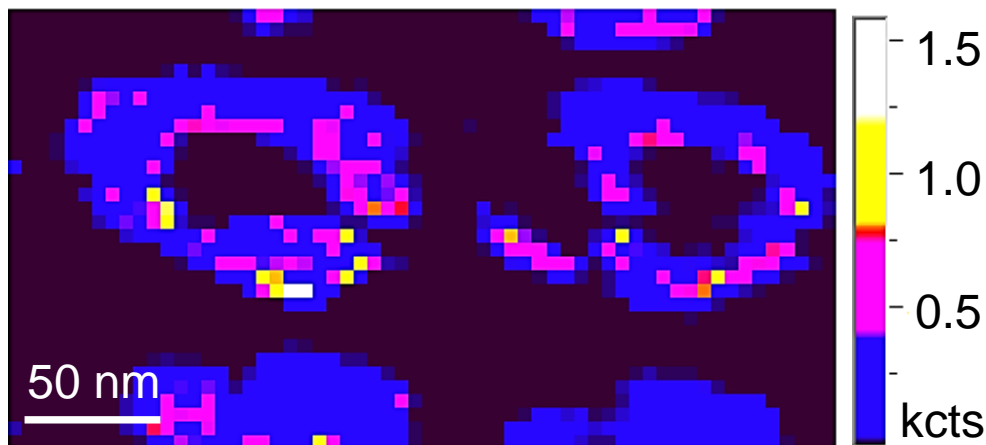
Topography



$$\begin{aligned}
 EF_{hot-spot} &= Contrast_{TERS} \times \left( \frac{R_{far}}{R_{hot-spot}} \right)^2 \\
 &= 5.1 \cdot 10^8
 \end{aligned}$$

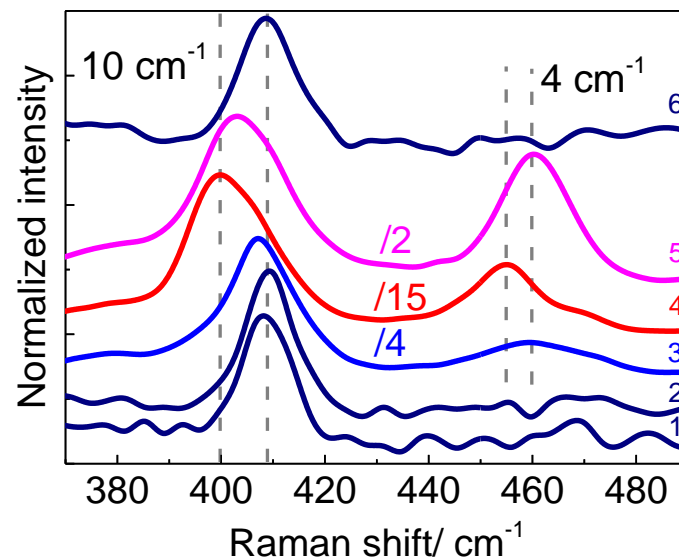
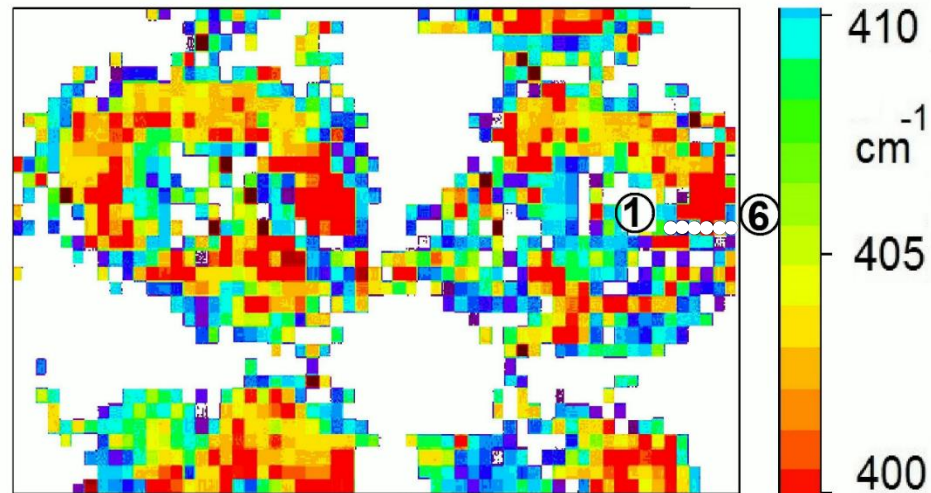
- Strain
- Temperature rise
- Hot electron doping

TERS map @ (390 – 430)  $\text{cm}^{-1}$

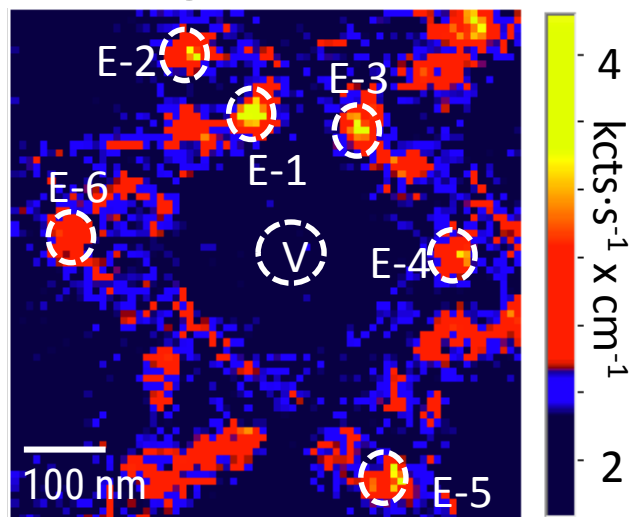


Milekhin *et al.*, *Nanoscale*, 10 2755 2018

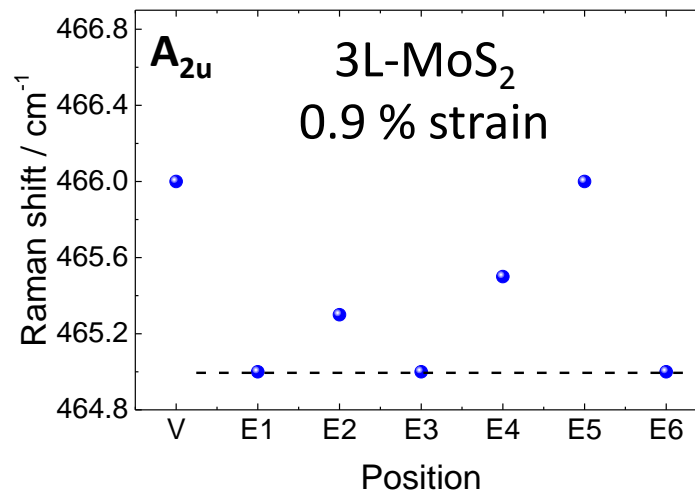
Peak position map



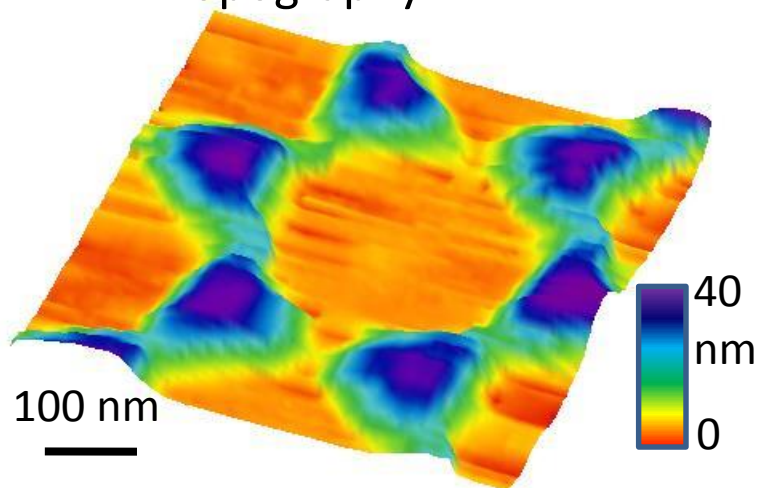
TERS image: @ (360 – 480)  $\text{cm}^{-1}$



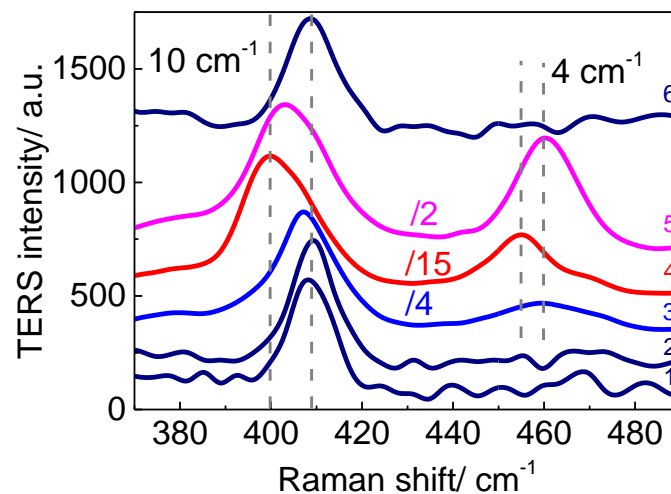
Raman shift due to strain



Topography



Strain induced shift  $\approx 2.2 \text{ cm}^{-1}$

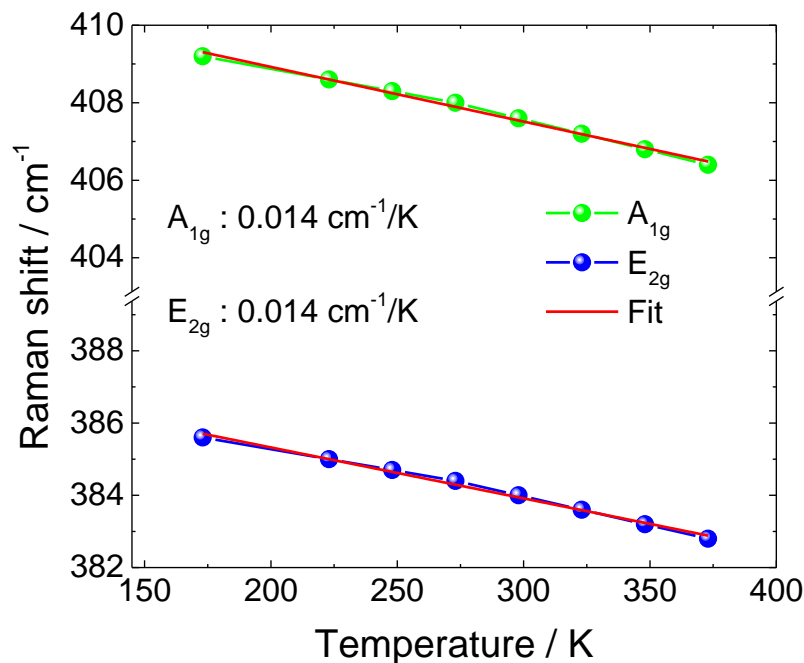
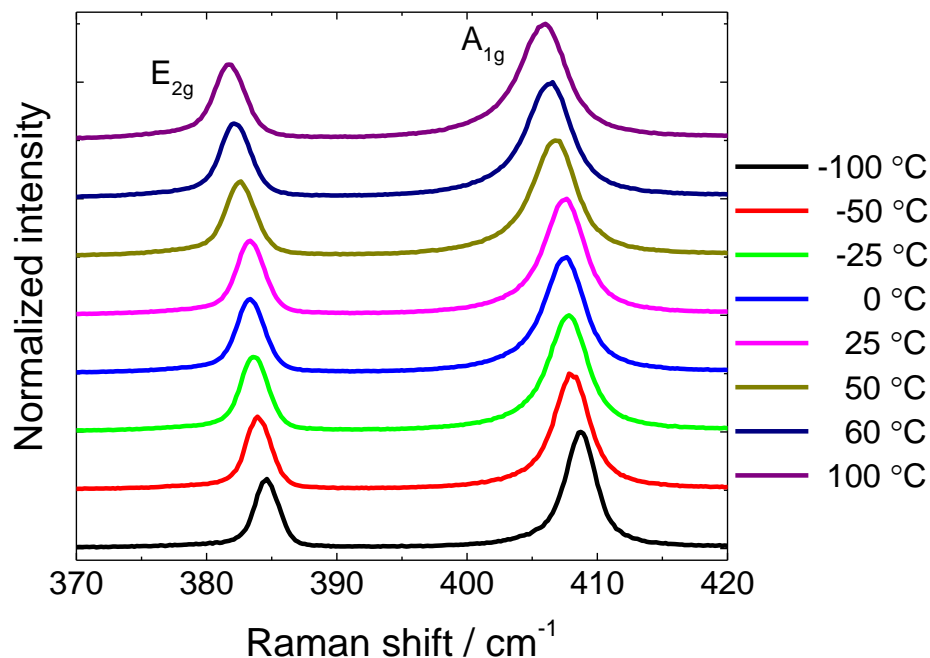


Rahaman *et al.*, *Nano Lett.*, (2017), 17, 6027

Local heating effect  $\approx 1.8 \text{ cm}^{-1}$



## Temperature dependent micro-Raman study of 3L-MoS<sub>2</sub>

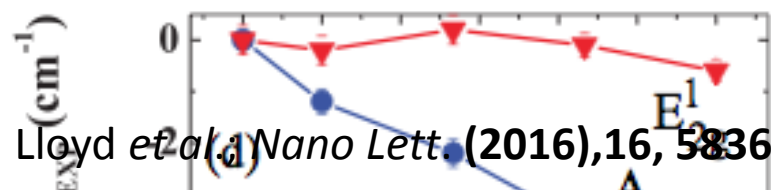


Temperature rise in the hot spots =  $\frac{1.8}{0.014} \approx 125 \text{ }^\circ\text{C}$

□ Doping induced Raman shift =  $6.7 \text{ cm}^{-1}$



Doping gradient of phonon modes



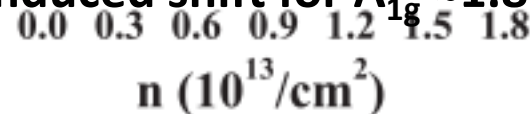
Lloyd *et al.* *Nano Lett.* (2016), 16, 5836

| Thickness | $E_{2g}^1$ mode shift rate ( $\text{cm}^{-1} / \%$ ) | $A_{1g}$ mode shift rate ( $\text{cm}^{-1} / \%$ ) |
|-----------|--|--|
| Monolayer | -5.2   | -1.7   |
| Bilayer   | -4.2   | -1.3   |
| Trilayer  | -3.0   | -0.7   |

Hot electron doping of  $1.6 \cdot 10^{13} \text{ cm}^{-2}$

0.9 % strain induced shift for  $A_{1g} \approx 1.5 \text{ cm}^{-1}$

Temperature induced shift for  $A_{1g} \approx 1.8 \text{ cm}^{-1}$



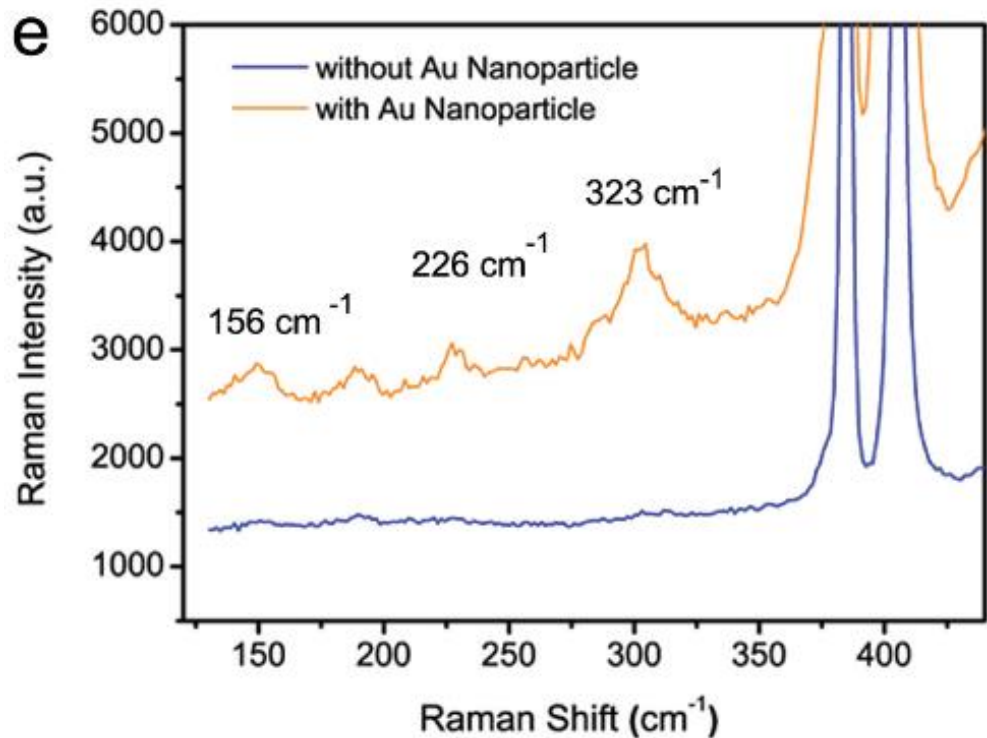
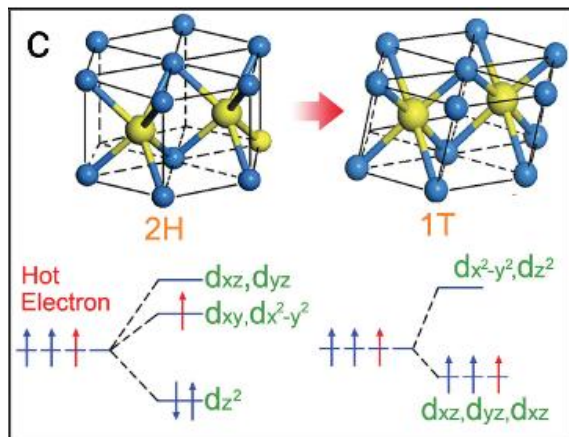
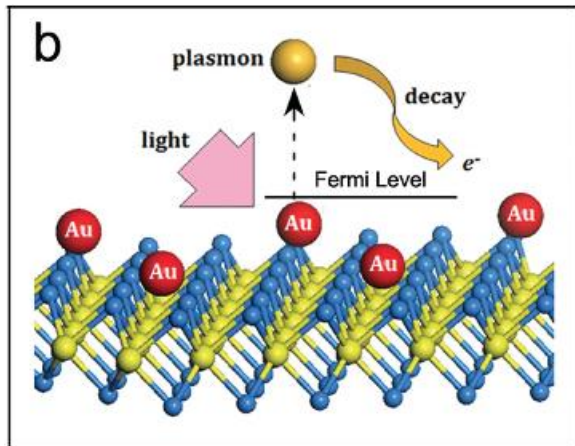
Chakraborty *et al.* *Phys. Rev. B* (2012), 85, 161403(R)

Doping gradient for

$A_{1g}$  mode =  $0.23 \cdot 10^{13} \text{ cm}^{-2} / \text{cm}^{-1}$

1. Li *et al.*; *ACS Nano* (2015), 9, 10158
2. Yu *et al.*, *Adv. Func. Mat.* (2016), 26, 6394
3. Najmaei *et al.*, *ACS Nano* (2014), 8, 12682

## Plasmonic hot electron induced phase transition

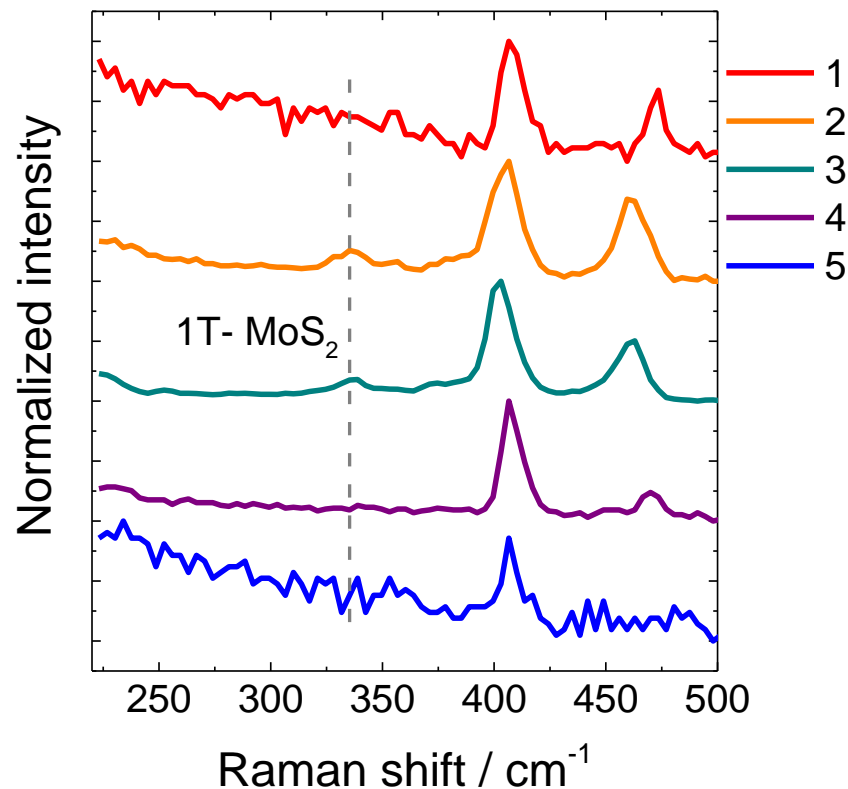
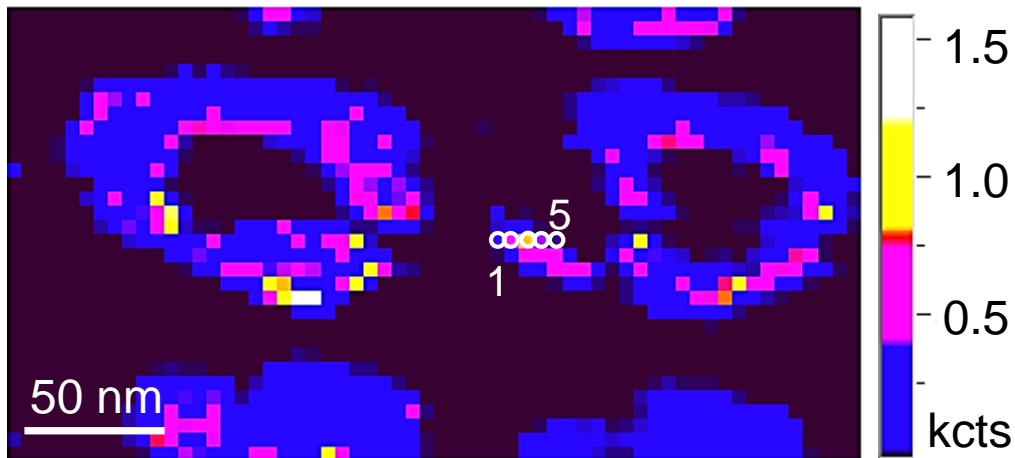


Kang *et al.* *Adv. Mat.* (2014), 2, 6467

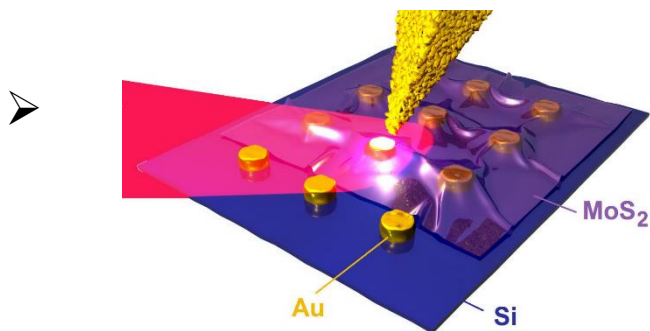
# Doping induced phase transition

## Plasmonic hot electron induced phase transition

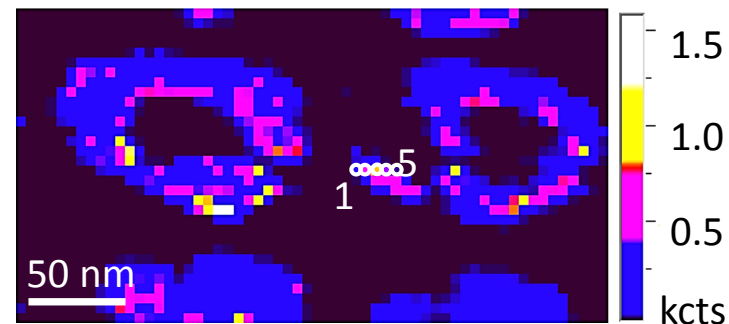
TERS map @ (390 – 430)  $\text{cm}^{-1}$



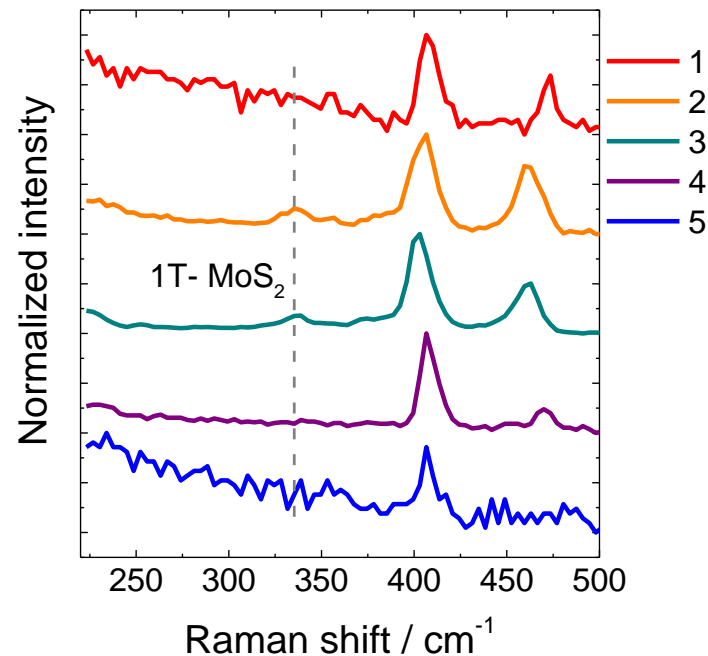
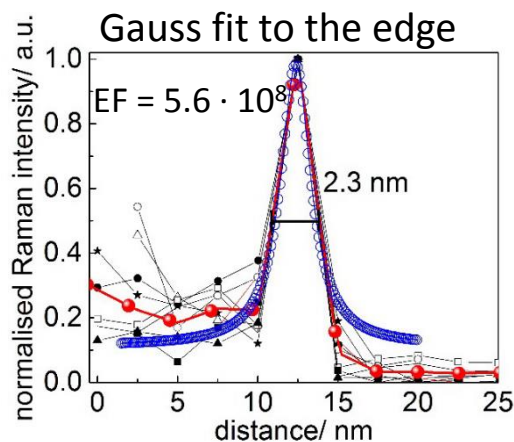
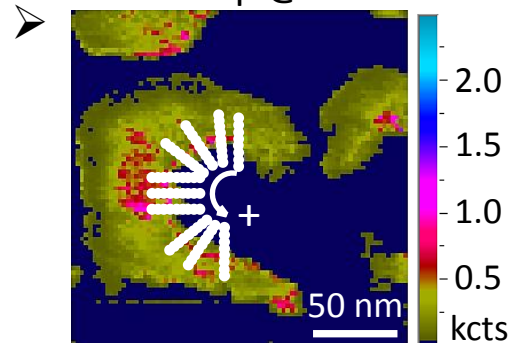
Milekhin *et al.*, *Nanoscale*, 10 2755 **2018**



TERS map @ 390 – 430  $\text{cm}^{-1}$



TERS map @ 410  $\text{cm}^{-1}$



- Estimated strain of 0.9 % and temperature rise of 125 °C
- Plasmonic hot electron doping concentration of  $1.6 \cdot 10^{13} \text{ cm}^{-2}$



**DFG Forschergruppe FOR 1497**  
Organisch-Anorganische Nanokomposite  
durch Zwillingspolymerisation



# Thank you for attention