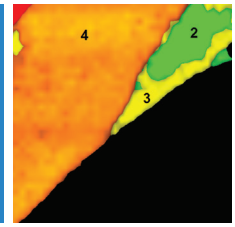
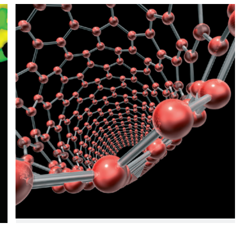
Raman Spectroscopy

# Number of layers of $MoS_2$ determined using Raman Spectroscopy



Application Note

Nanotechnology RA54

Renata Lewandowska, HORIBA Scientific, 231 rue de Lille, 59650 Villeneuve d'Ascq

Abstract
Presentation of two methods based on Raman spectroscopy for determining the number of layers of $MoS_2$.

Key words
$MoS_2$, Molybdenum disulfide, nanomaterials analysis, Raman spectroscopy, Raman imaging

## Layered low-dimensional structures

There are two types of vibrational modes in $MoS_2$ (as in all layered structures): vibrational modes inside layers (intralayer) and modes resulting from the movements of complete layers (interlayer). The intralayer modes are primary related to the chemical composition of a layer (or layers) and are their fingerprint; however these can be slightly influenced by the number of layers. The interlayer modes, due to the high mass of the layers, are observed at very low frequencies and their position depends on the number of layers. As a result, both types of modes can be used to determine the number of layers.

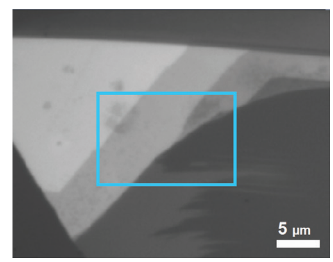



**Figure 1: Optical image of the $MoS_2$ sample. The blue rectangle corresponds to the mapped surface.**

The optical image of the sample of $MoS_2$ investigated here is shown on the left (courtesy of A. Shukla IMPMC, Pierre and Marie Curie University, France). The same sample was investigated already in [1].

## Method 1: Analysis of fingerprint modes (intralayer)

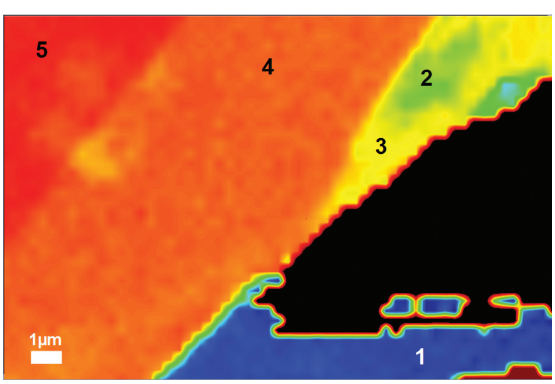



**Figure 2a: A Raman map of $MoS_2$ with different number of single layers based on the fingerprint modes analysis.**

The number of layers can be found by determining the distance between two fingerprint peaks (observed at ~383 $cm^{-1}$ and ~408 $cm^{-1}$

## Method 2: Analysis of low-frequency modes (interlayer)

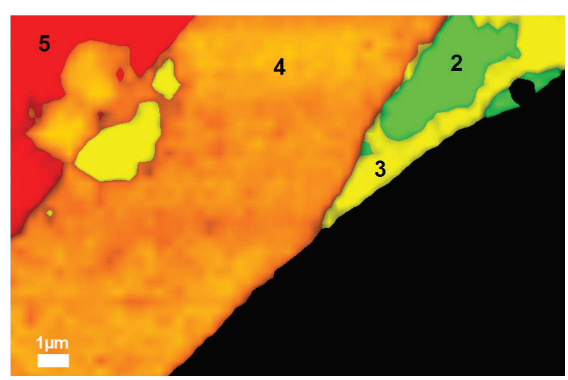



**Figure 3a: A Raman map of $MoS_2$ with different number of single layers based on low frequency modes analysis.**

The analysis is very straightforward and consists of mapping individual peaks corresponding to different number of single layers (the spectra

in bulk $MoS_2$ [2]). With increasing number of single layers the mode at ~383 $cm^{-1}$ shifts to lower frequencies and the mode at ~408 $cm^{-1}$ shifts to higher frequencies (figure 2b).
To obtain the image presented at the figure 2a, first, the fitting of peaks were done to find exact peak positions, than the difference between the peak positions were calculated and imaged. When the number of layers is higher than four the frequency of both peaks converge to the bulk values, which results in decreasing capacity of differentiating between the layers of different thickness.

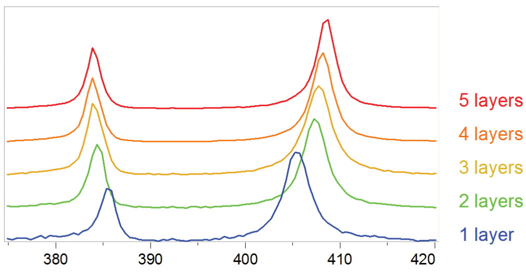



**Figure 2b: Raman spectra of $MoS_2$ in the fingerprint region.**

are shown in figure 3b). As they are relatively well resolved, a simple analysis using map cursors to follow peak intensities is sufficient; in this study CLS fitting was used for better contrast.
The interlayer modes appear below 35 $cm^{-1}$. In this analysis, the main shear mode was used; other peaks observed in this region correspond to secondary shear modes or to compression modes; they give additional information and allow the identification of number of layers without ambiguity. Their frequencies can be predicted taking into account the weight of a layer and shearing strength. More details can be found in refs. [1] and [3].

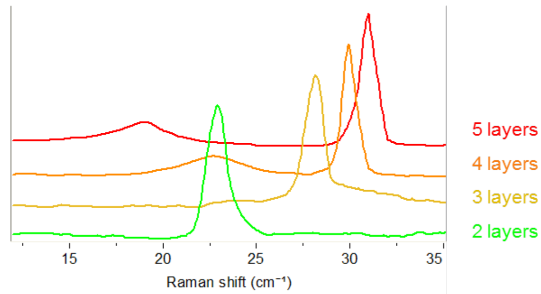



**Figure 3b: Raman spectra of $MoS_2$ in the low frequency region**

## Conclusions

The two methods give complementary results and allow the determination of the number of layers. Method 2 (using low frequency modes) gives excellent contrast; however it does not show single layer regions (which is related to the nature of the modes, rising from interaction between at least two layers). Method 1 (using fingerprint modes) shows all the layers, but the contrast is poorer, particularly for higher numbers of layers. The best result can be obtained combining the two methods:

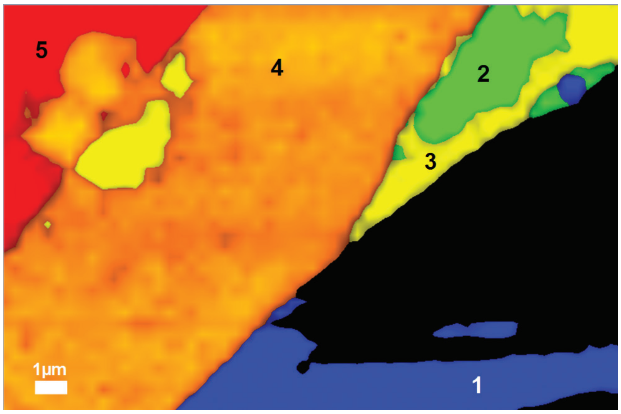



**Figure 4: A combined Raman map of $MoS_2$ layers.**

## Experimental details

All the measurements (low-frequency and fingerprint) were done using ultra-low frequency ULF™ filters which allow a high throughput measurement in a full Raman range, down to <10 $cm^{-1}$ (http://www.horiba.com/scientific/products/raman-spectroscopy/accessories/ultra-low-frequency-raman-module/).

## Further reading

1. M. Boukhicha at al., Phys. Rev. **B87** (2013) 195316.
2. H.Li at al., Adv. Funct. Mater. **22** (2012) 1385.
3. F. Bonaccorso at al., ACSNano **7** (2013) 1838.
4. H. Zeng at al., Phys. Rev. **B86** (2012) 241301.
5. X. Zang at al., Phys. Rev. **B87** (2013) 115413.
6. C. Lee at al., ACS Nano **4** (2010) 2695.