



Chemistry A European Journal

 **Chemistry
Europe**
European Chemical
Societies Publishing

Accepted Article

Title: Covalent cross-linking of 2H-MoS₂ nanosheets

Authors: Manuel Vázquez Sulleiro, Ramiro Quirós-Ovies, Mariano Vera-Hidalgo, I. Jénifer Gómez, Víctor Sebastián, Jesús Santamaría, and Emilio M. Pérez

This manuscript has been accepted after peer review and appears as an Accepted Article online prior to editing, proofing, and formal publication of the final Version of Record (VoR). This work is currently citable by using the Digital Object Identifier (DOI) given below. The VoR will be published online in Early View as soon as possible and may be different to this Accepted Article as a result of editing. Readers should obtain the VoR from the journal website shown below when it is published to ensure accuracy of information. The authors are responsible for the content of this Accepted Article.

To be cited as: *Chem. Eur. J.* 10.1002/chem.202004366

Link to VoR: <https://doi.org/10.1002/chem.202004366>

WILEY-VCH

Covalent cross-linking of 2H-MoS₂ nanosheets

Manuel Vázquez Sulleiro,^[a] Ramiro Quirós-Ovies,^[a] Mariano Vera-Hidalgo,^[a] I. Jéniffer Gómez,^[b] Víctor Sebastián,^{[c],[d]} Jesús Santamaría,^{*[c],[d],[e]} and Emilio M. Pérez^{*[a]}

[a] Dr. M. V. Sulleiro, R. Quirós-Ovies, M. Vera-Hidalgo, Prof. E. M. Pérez
IMDEA Nanociencia
C/Faraday 9 Ciudad Universitaria de Cantoblanco, 28049 Madrid, Spain
E-mail: emilio.perez@imdea.org

[b] Dr. I. J. Gómez
CEITEC Masaryk University
Kamenice 5, 625 00 Bmo, Czech Republic

[c] Dr. V. Sebastián, Prof. J. Santamaría
Institute of Nanoscience of Aragón (INA) and Department of Chemical and Environmental Engineering
Campus Río Ebro, 50018 Zaragoza, Spain
E-mail: jesus.santamaria@unizar.es

[d] Dr. V. Sebastián, Prof. J. Santamaría
Instituto de Ciencia de Materiales de Aragón (ICMA), Consejo Superior de Investigaciones Científicas (CSIC-Universidad de Zaragoza)
Zaragoza, Spain

[e] Prof. J. Santamaría
Networking Research Center on Bioengineering, Biomaterials and Nanomedicine (CIBER-BBN)
28029 Madrid, Spain

Supporting information for this article is given via a link at the end of the document.

Abstract: The combination of 2D materials opens a wide range of possibilities to create new generation structures with multiple applications. Covalently cross-linked approaches are a groundbreaking strategy for the formation of homo or heterostructures made by design. However, the covalent assembly of transition metal dichalcogenides flakes is relatively underexplored. Here, a simple covalent cross-linking method to build 2H-MoS₂-MoS₂ homostructures is described, using commercially available bismaleimides. These assemblies are majoritarily connected vertically, basal plane to basal plane, creating specific molecular sized spaces between MoS₂ sheets. This straightforward approach, therefore, gives access to the controlled connection of sulfide-based 2D materials.

The stack of different 2D materials^[1-6] is the root of the field of van der Waals heterostructures.^[7] The most widespread method for the synthesis of heterostructures of bidimensional materials is the direct growth of one material on top of the other by chemical vapor deposition or van der Waals epitaxy.^[8] Alternatively, one can manually stack one material on top of the other, using deterministic transfer methodologies.^[9-14] These methods are limited to interfacing the 2D materials through van der Waals forces.

There are very few synthetic methods of building 2D-2D homo/heterostructures that allow for precise control of the distance and chemical nature of the interface between materials, which directly determines their electronic communication and is, therefore, crucial for function.^[15, 16]

Covalently cross-linked structures are a very attractive strategy for the formation of homo/heterostructures made by design, with control over the size and chemical nature of the crosslinker.^[15, 16] This type of approach has been explored for cross-linked homostructures of carbon nanotubes (1D-1D)^[17-20] and graphene derivatives (2D-2D),^[21-23] as well as mixed-dimensional heterostructures of fullerenes and graphene derivatives (0D-2D)^[24-26] and carbon nanotubes and graphene oxide (1D-2D).^[27, 28] In comparison with the C-based nanomaterials, the covalent cross-

linking of transition metal dichalcogenides (TMDCs) is relatively underexplored, most likely due to a less developed, even if quickly growing, toolbox of chemical reactions for the covalent modification of TMDCs.^[29-36] Seminal work by C. N. Rao has described the covalent connection of MoS₂ with borocarbonitrides and C₃N₄ with remarkable catalytic activity,^[37, 38] and the formation of MoS₂-MoS₂ homostructures through a two-step Sonogashira coupling reaction.^[39]

Recently, we presented a “click” method for the covalent functionalization of 2H-MoS₂, based on the presence of a soft nucleophile (the sulphur of MoS₂ structure) which can attack the double bond of maleimide derivatives, resulting in the formation of a chemical C-S bond between the material and the organic moiety.^[40, 41]

Here, we present the formation of covalently linked MoS₂-MoS₂ homostructures in suspension, using the MoS₂-maleimide “click” reaction. Few layer colloids of MoS₂ were obtained through liquid phase exfoliation (LPE) in N-Methyl-2-pyrrolidone (NMP) using an ultrasonic probe (1h). The supernatant exfoliated material was separated from bulk through centrifugation (See SI, general procedures). The resulting 2H-polytype MoS₂ was characterized by UV-Vis, Raman spectroscopy and XRD.^[41] The flakes showed a majority height profile below 12 nm (Figure S1) determined by AFM and a larger dimension of 374±125 nm on average, as determined by TEM measurements. To connect the MoS₂ flakes, the colloids were transferred to acetonitrile, then we added commercially available bis-maleimide **1**, and the mixture was vigorously stirred overnight, to generate a covalently linked MoS₂-succ-succ-MoS₂ homostructure (Figure 1). The dispersion was filtered and washed several times using acetonitrile and isopropanol. The residues were checked by UV-Vis, confirming the total elimination of the physisorbed reagent after several washes (Figure S2). The resulting powder was dried and characterized exhaustively.

COMMUNICATION



Figure 1. General scheme of the formation of MoS₂-succ-succ-MoS₂ homostructure.

ATR-FTIR of the functionalized material (MoS₂-succ-succ-MoS₂, blue trace in Figure 2a) revealed the presence of the vibrational mode of carbonyl stretch in the surface of MoS₂-succ-succ-MoS₂ (1715 cm⁻¹), which is not present in either unreacted exfoliated material (*p*-MoS₂) or in a control sample experiment (*cs*-MoS₂), in which MoS₂ was subjected to the same reaction and purification process without the presence of **1** (black and red traces in Figure 2a, respectively). Moreover, we observe the disappearance of the sp² C-H bending of the alkene in **1** (821 cm⁻¹, green trace in Figure 2a). Besides, a new band related by the generation of the C-S bond was observed at 729 cm⁻¹, confirming the linking between the organic moiety and the surface of MoS₂.^[40]

Thermogravimetric analysis showed significant differences between the functionalized and control sample (Figure 2b). In the case of MoS₂-succ-succ-MoS₂, derivative weight shows a new maximum between 210 and 320 °C, which we assign to the organic anchor; a second, slow, two-step decomposition between 350 °C and 550 °C is also observed and correlates well with the oxidation of MoS₂. In addition, at 550 °C the differences in the thermal decomposition of the functionalized material against its unreacted exfoliated material is 6%. In comparison, *cs*-MoS₂ did not show any difference with the exfoliated material (compare black and red traces in Figure 2b). TGA under N₂ flow showed similar weight loss (Figure S3) with shifted variation in the thermal decomposition in the case of the homostructure MoS₂-succ-succ-MoS₂. XRD showed slight differences in the functionalization of the material (Figure S4). The XRD patterns of as-prepared exfoliated MoS₂ and MoS₂-succ-succ-MoS₂, are in good agreement with the standard data for MoS₂.^[42] No extra characteristic peaks from the organic moiety or the homostructure were detected, which may be because of its relatively low diffraction intensity compared to that of MoS₂. Resonant Raman spectroscopy measurements (λ_{exc} = 633 nm) showed clearly that the exfoliated material is few-layer 2H-MoS₂ polytype, and remains as such after functionalization, with the characteristic E¹_{2g}, A_{1g}, and 2LA(M) modes. Besides, the relative intensity of the 2LA(M) mode of MoS₂-succ-succ-MoS₂ showed a decrease compared to the unreacted exfoliated material, which can be connected to an increase in number of layers/vertical size (Figure S5).^[43, 44]

The anchor of a chemical moiety onto the surface of MoS₂ with a bismaleimide functional group, allows the formation of vertical homostructures of MoS₂-succ-succ-MoS₂. Such covalent cross-

linking involves a significant increase in particle size, which is clearly reflected as a significant increase on the scattering contribution observed in the extinction spectra, and a red shift on the excitonic peaks of MoS₂, in MoS₂-succ-succ-MoS₂ compared to *p*-MoS₂ and *cs*-MoS₂ (Figure 2c).^[45]

Finally, XPS analysis showed the presence of N (1.9%), onto the surface of the functionalized material, while neither *p*-MoS₂ nor *cs*-MoS₂ showed detectable amounts of N (Figure 2d, Figure S6, Table S1). The relation with the modified sulphurs (4%) of the material would correspond to a 9% weight loss in TGA, see Eq. S1, which is in good agreement with our TGA data.

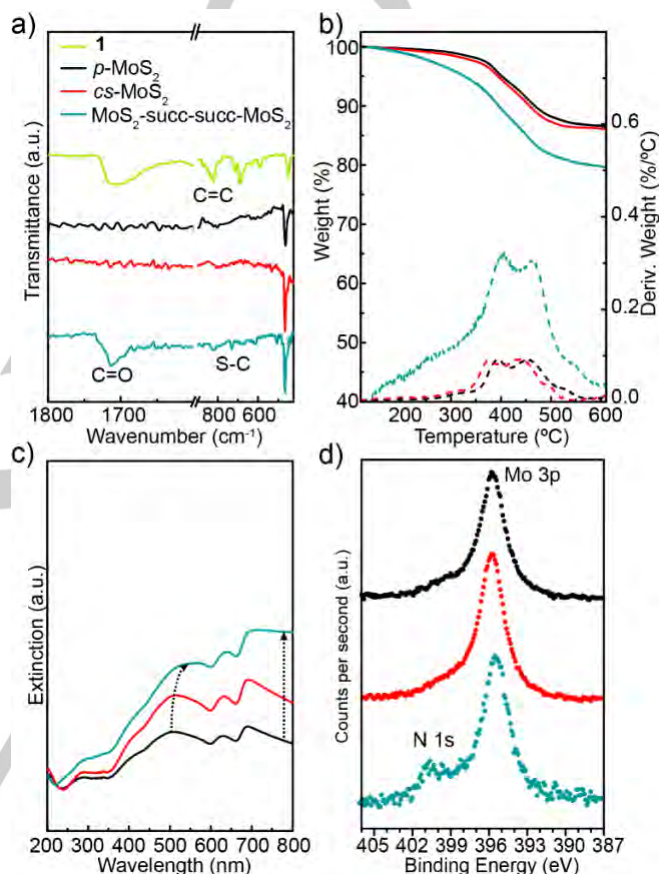


Figure 2. a) ATR-FTIR of bismaleimide **1** (green), unreacted exfoliated MoS₂ (black), MoS₂-succ-succ-MoS₂ (blue) and control sample MoS₂ (red). b) TGA (air, 10 °C min⁻¹) of *p*-MoS₂, *cs*-MoS₂ and MoS₂-succ-succ-MoS₂ c) UV-VIS of unreacted exfoliated MoS₂ (black), MoS₂-succ-succ-MoS₂ (blue) and control sample experiment (red). d) XPS core level of N 1s comparison between unreacted exfoliated MoS₂ (black), MoS₂-succ-succ-MoS₂ (blue) and control sample experiment (red)

AFM analysis of hundreds of flakes of the different samples spin-coated from acetonitrile, showed a clear increase in the thickness of the flakes in the case of MoS₂-succ-succ-MoS₂ with respect to *p*-MoS₂ (Figure 3a). However, the formation of the homostructure did not modify the lateral size of the sample significantly, indicating that a vertical cross-linking of MoS₂ was the favored mode of reaction, in line with preferential functionalization of MoS₂ basal planes. Remarkably, this thickness increase is observed only when the reaction is carried out with two maleimide anchor points that can react with the material, it was not observed in the reaction with other maleimides previously studied in our group or

COMMUNICATION

in the control sample experiment (Figure S7).^[40, 41] In a closer look, AFM profiles of specific flakes of MoS₂-succ-succ-MoS₂ often showed a two-step profile, confirming the presence of two or more flakes connected vertically, while such pattern is rarely observed in *p*-MoS₂ (compare insets in Figure 3b and c).

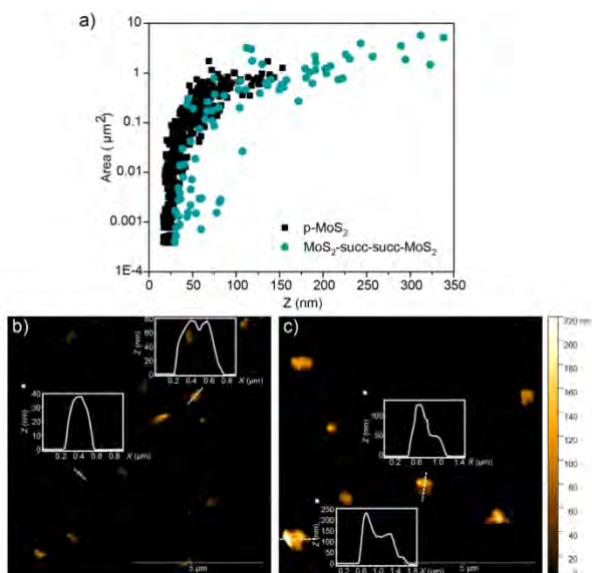


Figure 3. a) Scatter plot of area (μm^2) vs height (nm) of unreacted exfoliated MoS₂ (black) and MoS₂-succ-succ-MoS₂ (blue), b) AFM images and height profiles of unreacted exfoliated MoS₂ and c) MoS₂-succ-succ-MoS₂.

A FEI Titan™ microscope working at an acceleration voltage of 300 kV was employed for the characterization of MoS₂ flakes through electron microscopy. A 10 μL suspension of the MoS₂ flakes dispersed in DMSO was drop-casted onto 200 square mesh copper holey carbon TEM grid and then dried overnight. Spherical aberration corrected HAADF-HRSTEM measurements are shown in Figure 4. Examination of the unreacted exfoliated and functionalized MoS₂-succ-succ-MoS₂ showed a variety of interlayer spacing. Thus, for the control sample a periodic interlayer spacing of 0.65 nm is consistently observed (Figure 4a). On the other hand, for the functionalized samples, we find both flakes that did not react and kept the original spacing (Figure 4b) and, frequently in other cases, a spacing around 1.1 nm can be observed between two flakes. Note that image contrast in HAADF-STEM is inversely correlated with the atomic mass, so the lighter elements in the organic fragment (C, H, N, O) are expected to appear dark when compared to the heavier Mo and S. These results correspond reasonably well to the estimated distance between two small fragments of MoS₂ separated by 1 (1.3 nm, according to molecular mechanics calculations, see Figure S8). These results are one more clear indication of the covalent cross-linking MoS₂ flakes (See Figure S9).

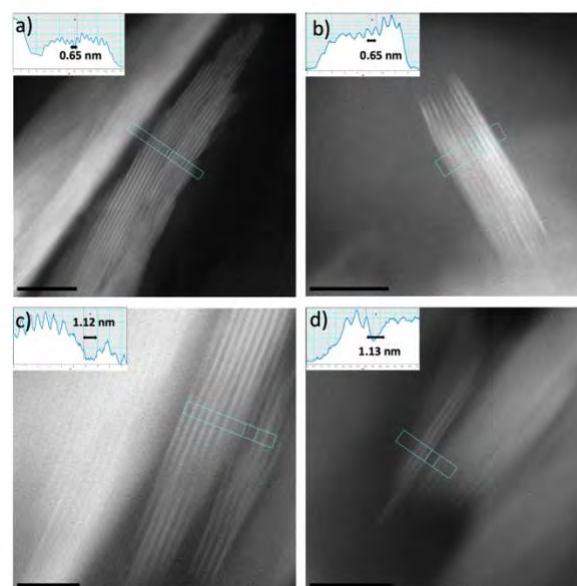


Figure 4. High-angle annular-dark-field scanning transmission electron microscopy (HAADF-STEM) images of MoS₂ a) control experiment, b) isolated flake of functionalized MoS₂ c) and d) cross-linked flakes of MoS₂-succ-succ-MoS₂. Scale bar 5 nm.

In summary, a simple methodology to covalently connect flakes of MoS₂ for the generation of vertical MoS₂-MoS₂ homostructures was developed, using commercially available bismaleimide reagent. The new material showed an increase of the thickness of the nanosheets without significant changes in the lateral size as a reliable indicator of the vertical growth of the homostructure. We believe that this approach opens up many possibilities to connect other sulfide-based 2D materials through covalent bonds, with control of the interlayer distance, as a complementary approach to van der Waals homo/heterostructures.^[46] Potential applications include the increase of conductivity or extinction coefficient or photoresponsivity of the active material in TMDC devices, while conserving the electronic properties of the monolayer material.

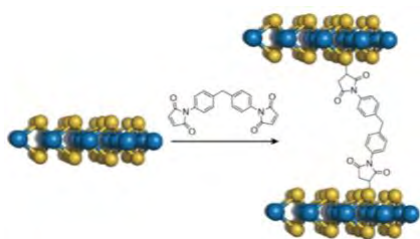
Acknowledgements

The European Research Council (ERC-StG-307609; ERC-PoC-842606; ERC-AdG-742684), MINECO (CTQ2017-86060-P and CTQ2016-79419-R) the Comunidad de Madrid (MAD2D-CM S2013/ MIT-3007), CzechNanoLab Research Infrastructure supported by MEYS CR (LM2018110) are gratefully acknowledged. IMDEA Nanociencia acknowledges support from the “Severo Ochoa” Programme for Centres of Excellence in R&D (MINECO, Grant SEV- 2016-0686).

There are no conflicts to declare.

Keywords: 2D materials • covalent homostructure • MoS₂ • covalent functionalization

- [1] A. C. Ferrari, F. Bonaccorso, V. Fal'ko, K. S. Novoselov, S. Roche, P. Boggild, S. Borini, F. H. L. Koppens, V. Palermo, N. Pugno, J. A. Garrido, R. Sordan, A. Bianco, L. Ballerini, M. Prato, E. Lidorikis, J. Kivioja, C. Marinelli, T. Ryhanen, A. Morpurgo, J. N. Coleman, V. Nicolosi, L. Colombo, A. Fert, M. Garcia-Hernandez, A. Bachtold, G. F. Schneider, F. Guinea, C. Dekker, M. Barbone, Z. Sun, C. Galiotis, A. N. Grigorenko, G. Konstantatos, A. Kis, M. Katsnelson, L. Vandersypen, A. Loiseau, V. Morandi, D. Neumaier, E. Treossi, V. Pellegrini, M. Polini, A. Tredicucci, G. M. Williams, B. Hee Hong, J.-H. Ahn, J. Min Kim, H. Zirath, B. J. van Wees, H. van der Zant, L. Occhipinti, A. Di Matteo, I. A. Kinloch, T. Seyller, E. Quesnel, X. Feng, K. Teo, N. Rupesinghe, P. Hakonen, S. R. T. Neil, Q. Tannock, T. Lofwander, J. Kinaret, *Nanoscale* **2015**, *7* (11), 4598-4810.
- [2] K. S. Novoselov, A. K. Geim, S. V. Morozov, D. Jiang, Y. Zhang, S. V. Dubonos, I. V. Grigorieva, A. A. Firsov, *Science* **2004**, *306* (5696), 666-669.
- [3] M. Xu, T. Liang, M. Shi, H. Chen, *Chem. Rev.* **2013**, *113* (5), 3766-3798.
- [4] A. Pakdel, Y. Bando, D. Golberg, *Chem. Soc. Rev.* **2014**, *43* (3), 934-959.
- [5] R. Lv, J. A. Robinson, R. E. Schaak, D. Sun, Y. Sun, T. E. Mallouk, M. Terrones, *Acc. Chem. Res.* **2015**, *48* (1), 56-64.
- [6] A. Castellanos-Gomez, L. Vicarelli, E. Prada, J. O. Island, K. L. Narasimha-Acharya, S. I. Blanter, D. J. Groenendijk, M. Buscema, G. A. Steele, J. V. Alvarez, H. W. Zandbergen, J. J. Palacios, H. S. J. van der Zant, *2D Mater.* **2014**, *1* (2), 25001/1-25001/19.
- [7] Y. Liu, N. O. Weiss, X. Duan, H.-C. Cheng, Y. Huang, X. Duan, *Nat. Rev. Mater.* **2016**, *1*, 16042.
- [8] J. A. Robinson, *ACS Nano* **2016**, *10* (1), 42-45.
- [9] A. Castellanos-Gomez, M. Buscema, R. Molenaar, V. Singh, L. Janssen, H. S. J. van der Zant, G. A. Steele, *2D Mater.* **2014**, *1* (1), 011002/1-011002/8, 8 pp.
- [10] Y. Liu, N. O. Weiss, X. Duan, H.-C. Cheng, Y. Huang, X. Duan, *Nat. Rev. Mater.* **2016**, *1* (9), 16042.
- [11] M. Yankowitz, Q. Ma, P. Jarillo-Herrero, B. J. LeRoy, *Nat. Rev. Phys.* **2019**, *1*.
- [12] G. P. Neupane, K. Zhou, S. Chen, T. Yildirim, P. Zhang, Y. Lu, *Small* **2019**, *15* (11), 1804733.
- [13] K. Novoselov, A. Mishchenko, A. Carvalho, A. C. Neto, *Science* **2016**, *353* (6298), aac9439.
- [14] D. Jariwala, T. J. Marks, M. C. Hersam, *Nat. Mater.* **2017**, *16* (2), 170.
- [15] C. Rao, K. Pramoda, R. Kumar, *Chem. Commun.* **2017**, *53* (73), 10093-10107.
- [16] R. Kumar, V. M. Suresh, T. K. Maji, C. Rao, *Chem. Commun.* **2014**, *50* (16), 2015-2017.
- [17] R. Kumar, C. Rao, *J. Mater. Chem. A* **2015**, *3* (13), 6747-6750.
- [18] M. Barrejón, R. Rauti, L. Ballerini, M. Prato, *ACS nano* **2019**, *13* (8), 8879-8889.
- [19] M. Barrejón, Z. Syrgiannis, M. Burian, S. Bosi, T. Montini, P. Fornasiero, H. Amenitsch, M. Prato, *ACS Appl. Mater. Interfaces* **2019**, *11* (13), 12920-12930.
- [20] Schirowski, M.; Abellán, G.; Nuin, E.; Pampel, J.; Dolle, C.; Wedler, V.; Fellinger, T.-P.; Spiecker, E.; Hauke, F.; Hirsch, A., *J. Am. Chem. Soc.* **2018**, *140* (9), 3352-3360.
- [21] K. Yuan, Y. Xu, J. Uihlein, G. Brunklaus, L. Shi, R. Heiderhoff, M. Que, M. Forster, T. Chassé, T. Pichler, *Adv. Mater.* **2015**, *27* (42), 6714-6721.
- [22] G. Srinivas, J. W. Burrell, J. Ford, T. Yildirim, *J. Mater. Chem.* **2011**, *21* (30), 11323-11329.
- [23] B. Yao, C. Li, J. Ma, G. Shi, *Phys. Chem. Chem. Phys.* **2015**, *17* (29), 19538-19545.
- [24] Q. Chen, M.-Q. Cheng, K. Yang, W.-Q. Huang, W. Hu, G.-F. Huang, *J. Phys. D: Appl. Phys.* **2018**, *51* (30), 305301.
- [25] D. García, L. Rodríguez-Pérez, M. Herranz, D. Peña, E. Guitián, S. Bailey, Q. Al-Galiby, M. Noori, C. J. Lambert, D. Pérez, *Chem. Commun.* **2016**, *52* (40), 6677-6680.
- [26] Barrejón, M.; Vizuete, M.; Gómez-Escalonilla, M. J.; Fierro, J. G.; Berlanga, I.; Zamora, F.; Abellán, G.; Atienzar, P.; Nierengarten, J.-F.; García, H., *Chem. Commun.* **2014**, *50* (65), 9053-9055.
- [27] L.-Y. Lin, M.-H. Yeh, J.-T. Tsai, Y.-H. Huang, C.-L. Sun, K.-C. Ho, *J. Mater. Chem. A* **2013**, *1* (37), 11237-11245.
- [28] Wei, T.; Hauke, F.; Andreas, H., *Acc. Chem. Res.* **2019**, *52* (8), 2037-2045.
- [29] S. Bertolazzi, M. Gobbi, Y. Zhao, P. Samori, C. Backes, *Chem. Soc. Rev.* **2018**, *47* (17), 6845-6888.
- [30] S. Ippolito, A. Ciesielski, P. Samori, *Chem. Commun.* **2019**, *55* (61), 8900-8914.
- [31] M. Chhowalla, H. S. Shin, G. Eda, L.-J. Li, K. P. Loh, H. Zhang, *Nat. Chem.* **2013**, *5*, 263.
- [32] S. Karunakaran, S. Pandit, B. Basu, M. De, *J. Am. Chem. Soc.* **2018**, *140* (39), 12634-12644.
- [33] R. Canton - Vitoria, H. B. Gobeze, V. M. Blas - Ferrando, J. Ortiz, Y. Jang, F. Fernández - Lázaro, Á. Sastre - Santos, Y. Nakanishi, H. Shinohara, F. D'Souza, *Angew. Chem. Int. Ed.* **2019**, *131* (17), 5768-5773.
- [34] S. Bertolazzi, S. Bonacchi, G. Nan, A. Pershin, D. Beljonne, P. Samori, *Adv. Mater.* **2017**, *29* (18), 1606760.
- [35] A. Hirsch, F. Hauke, *Angew. Chem., Int. Ed.* **2018**, *57* (16), 4338-4354.
- [36] I. K. Sideri, R. Arenal, N. Tagmatarchis, *ACS Mater. Lett.* **2020**, *2* (7), 832-837.
- [37] K. Pramoda, M. M. Ayyub, N. K. Singh, M. Chhetri, U. Gupta, A. Soni, C. Rao, *J. Phys. Chem. C* **2017**, *122* (25), 13376-13384.
- [38] K. Pramoda, U. Gupta, M. Chhetri, A. Bandyopadhyay, S. Pati, C. Rao, *ACS Appl. Mater. Interfaces* **2017**, *9* (12), 10664-10672.
- [39] K. Pramoda, U. Gupta, I. Ahmad, R. Kumar, C. N. R. Rao, *J. Mater. Chem. A* **2016**, *4* (23), 8989-8994.
- [40] M. Vera-Hidalgo, E. Giovanelli, C. Navio, E. M. Perez, *J. Am. Chem. Soc.* **2019**, *141* (9), 3767-3771.
- [41] Quirós-Ovies, R.; Vázquez Sulleiro, M.; Vera-Hidalgo, M.; Prieto, J.; Gómez, I. J.; Sebastián, V.; Santamaría, J.; Pérez, E. M., *Chem. Eur. J.* **2020**, *26* (29), 6629-6634.
- [42] Liu, Y.; Zhao, Y.; Jiao, L.; Chen, J., *J. Mater. Chem. A* **2014**, *2* (32), 13109-13115.
- [43] G. L. Frey, R. Tenne, M. J. Matthews, M. S. Dresselhaus, G. Dresselhaus, *Phys. Rev. B* **1999**, *60* (4), 2883-2892.
- [44] B. Chakraborty, H. S. S. R. Matte, A. K. Sood, C. N. R. Rao, *J. Raman Spectrosc.* **2013**, *44* (1), 92-96.
- [45] C. Backes, R. J. Smith, N. McEvoy, N. C. Berner, D. McCloskey, H. C. Nerl, A. O'Neill, P. J. King, T. Higgins, D. Hanlon, N. Scheuschner, J. Maultzsch, L. Houben, G. S. Duesberg, J. F. Donegan, V. Nicolosi, J. N. Coleman, *Nat. Commun.* **2014**, *5*, 4576.
- [46] Y. Liu, Y. Huang, X. Duan, *Nature* **2019**, *567* (7748), 323-333.
- ...

Entry for the Table of Contents

The covalent combination of different flakes of 2D materials is relatively underexplored, in particular, in the case of transition metal dichalcogenides. This work reports a simple methodology of covalent cross-linking of MoS₂ through bismaleimide reagent. The MoS₂-MoS₂ homostructures show preferably a vertical connection, basal plane to basal plane of different flakes.

Institute and/or researcher Twitter usernames: [@emilioperezlab](#) [@MSulleiro](#) [@IMDEA_Nano](#)