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View Article Online
DOI: 10.1039/D0CC01092H

COMMUNICATION

Organic "Receptor" Fully Covered Few-layer Organic-metal Chalcogenide for High-Performance Chemiresistive Gas Sensing at Room Temperature†

Received 00th January 20xx,
Accepted 00th January 20xx

DOI: 10.1039/x0xx00000x

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Organic-metal chalcogenides (OMCs) are proposed as a new family of two-dimensional (2D) chemiresistive sensing materials. Few-layer Ag(SPh-NH$_2$), one of OMCs, fully and orderly covered with predesigned –NH$_2$ groups as "receptors", shows highest sensitivity, excellent selectivity and reversibility to NO$_2$ among all reported 2D chemiresistive sensing materials at room temperature.

Chemiresistors have attractive intensive research interest due to their fascinating features, such as high sensitivity, fast response, low fabrication cost, and real-time detection. Metal oxides are the dominant and key sensing materials for chemiresistive sensors. However, the applications of metal oxides sensors are significantly hampered by their unsatisfying selectivity and high operating tem-perature.[1-3] Therefore, it is of great importance to develop new sensing materials that possess high sensitivity and selectivity toward target gases for room temperature (RT) operation.

Two-dimensional (2D) materials, such as graphene and its derivatives,[4-5] transition metal dichalcogenides (TMDs),[6-8] black phosphorus (BP),[7-10] 2D metal-organic frameworks (MOFs),[11-20] 2D covalent-organic frameworks (COFs)[21] *etc.*, have obtained increasing attention as chemiresistive gas sensing materials.[22] Compared with their bulk counter-parts, 2D materials possess fascinating features for gas sensing, such as larger surface-to-volume ratio, more accessible active sites, better charge transport, and good processability,[23] which endow the thin films made from them with good gas sensing performance at RT[19-20,24-25]. We noticed that the sensitivity and selectivity of these 2D materials were significantly enhanced by modifying their surfaces with organic functional groups owing to the enhanced interactions between 2D materials and target gases.[26-28] For example, Shi's group reported that sulfanilic acid and ethylenediamine (S-G, EDA-G) treated reduced graphene oxide (rGO) materials showed 16.4 and 4.3 times higher responses to NO$_2$ than that of pristine rGO, respectively.[26] Compared with non-functionalized rGO, chemically fluorinated GO (CFGO) displayed enhanced selectivity between NH$_3$ and NO$_2$ by 3.65 times.[28] However, the known post-treated 2D materials normally have a relative low ratio of modified surface and inhomogeneous distribution of functional groups. This profoundly hinders us to achieve higher sensing performances with the known 2D materials and their derivatives.

Recently, a new type of semiconducting 2D materials, organic-metal chalcogenides (OMCs) are emerging.[29-30] these of other 2D materials, the surfaces of OMCs are fully and orderly covered by organic functional groups. Our previous work revealed that the conductivity of OMCs is very sensitive to the electronic structure of these organic groups. A change of 10^6 times on their conductivity was observed when varying the type of organic groups on them. Since the electronic structure of these organic groups would be influenced after adsorbing foreign gas molecules, we proposed that OMCs may possess hi-

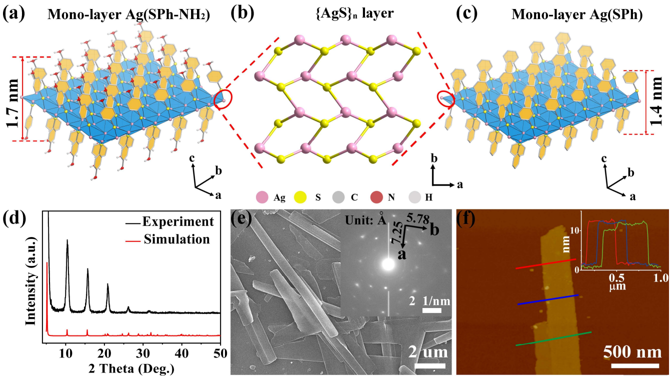

Fig. 1 (a), (c) Mono-layer structure of Ag(SPh-NH$_2$) and Ag(SPh). (b) 2D $\{AgS\}_n$ layer of Ag(SPh-NH$_2$) and Ag(SPh). Hydrogen atoms of benzene ring have been omitted for clarity. (d) Experimental and stimulated PXRD patterns of Ag(SPh-NH$_2$). (e) SEM image of few-layer Ag(SPh-NH$_2$), inset is its selected area electron diffraction. (f) Typical AFM image of few-layer Ag(SPh-NH$_2$).

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†Electronic Supplementary Information (ESI) available: [Experimental details, Fig. S1-S18, Tab. S1-S4 See DOI: 10.1039/x0xx00000x

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DOI: 10.1039/D0CC01092H

gh sensitivity as a chemiresistive sensing material at RT. More importantly, these organic functional groups of OMCs can be designed with the required structure to enhance their affinity to the target gas. Therefore, a "made to order" selectivity which is desired for sensing materials may be realized in OMCs.

Herein, we report the first study of OMCs which possess a very high ratio of organic functionalized surfaces as highly sensitive and selective RT chemiresistive gas sensing materials. As a proof-of-concept, a few-layer OMC, Ag(SPh-NH_2), was prepared for detecting NO_2. The 2D $\{AgS\}_n$ layers of Ag(SPh-NH_2) are fully covered by ordered –NH_2 groups. This design remarkably enhanced the sensitivity and selectivity of OMCs to NO_2 owing to –NH_2 groups can be regarded as "receptors" to strongly interact with NO_2 through hydrogen bond, acid-base interaction *etc*. As a result, at RT, the few-layer Ag(SPh-NH_2) thin film showed not only the highest sensitivity and fastest response & recovery speed among all reported 2D chemiresistive sensing materials and their modified derivatives, but also very unique selectivity among 12 commonly existed interference gases.

Few-layer Ag(SPh-NH_2) was directly synthesized by the coordination reaction between Ag ions and HSPh-NH_2 (4-Aminobenzenethiol) in hydrothermal condition at 85 °C. For control experiments, Ag(SPh) (HSPh = benzenethiol), an isostructure of Ag(SPh-NH_2), was prepared with a similar synthetic method (experimental details see ESI). The experimental powder X-ray diffraction pattern (PXRD) of Ag(SPh-NH_2) and Ag(SPh) are in good agreement with their simulated or reported ones, verifying their phase purity (Fig. 1d and Fig. S1).[31] Fourier transform infrared spectroscopy (FT-IR) and elemental analysis measurements further confirmed their structures and purities (Fig. S2-3, Tab. S1).

In the structure of mono-layer Ag(SPh-NH_2) and Ag(SPh) (Fig. 1a,c), each Ag^+ ion coordinates with three μ_3-bridging S atoms in a trigonal planar configuration to form a distorted honeycomb 2D $\{AgS\}_n$ layer (Fig. 1b). The organic functional groups alternatively and covalently bond to S atoms on the top and bottom surfaces of $\{AgS\}_n$ layer. The thickness of mono-layer Ag(SPh-NH_2) and Ag(SPh) is ~1.7 nm and 1.4 nm, respectively. These mono-layers are parallelly packing with each other along c axis to form few-layer Ag(SPh-NH_2) and Ag(SPh) (Fig. S4-5). The +1 valence of Ag was confirmed by the high-resolution X-ray photoelectron spectroscopy (XPS) spectra of few-layer Ag(SPh-NH_2) and Ag(SPh). Meanwhile, the binding energy of N1s for Ag(SPh-NH_2) was determined to be ~400 eV which is the same as that of phenylamine, suggesting that the amine groups on the surface of few-layer Ag(SPh-NH_2) are accessible to target gas molecules (Fig. S6-7).[32]

Scanning electron microscopy (SEM) measurements revealed that the nanobelt morphology of as-prepared few-layer Ag(SPh-NH_2) with a length of several micrometers and a width of ~500 nanometers (Fig. 1e). The selected area electron diffraction pattern of TEM showed sharp and ordered spot arrays, indicating the good crystallinity of few-layer Ag(SPh-NH_2) (insert of Fig. 1e). The plane distances were measured to be 7.25 Å and 5.78 Å along *a* and *b* directions, respectively, which consist well with the simulated results.[33] Atomic force microscope (AFM) measurement showed the average thickness of few-layer Ag(SPh-NH_2) is ~11 nm, indicating the stack of ~6 molecule layers (Fig. 1f). Likewise, the plate morphology of as-prepared few-layer Ag(SPh) was confirmed with an average thickness of ~20 nm (Fig. S8-9).

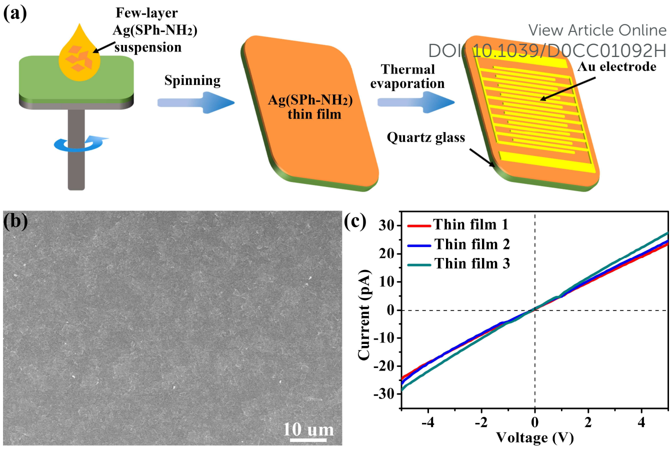

Fig. 2 (a) Fabrication of Ag(SPh-NH_2) thin film for gas sensing test. (b) Typical HR-SEM of the prepared Ag(SPh-NH_2) thin films. (c) I-V curves of Ag(SPh-NH_2) thin films.

The electrical and optical characterizations reveal that Ag(SPh-NH_2) is a p-type semiconductor with a conductivity of $6*10^{-7}$ S cm^{-1} at RT and a band gap of 2.62 eV, respectively.[30] The sensing performances of few-layer Ag(SPh-NH_2) were evaluated by preparing it into thin film on quartz substrates through conventional spin-coating method and then depositing patterned gold on it as interdigital electrodes via thermal evaporation (Fig. 2a, details see ESI). These thin films have continuous and homogeneous morphology (Fig. 2b). They also showed similar conductivity and ohmic contact with gold electrodes, indicating their good reproducibility (Fig. 2c). The sensing tests of few-layer Ag(SPh-NH_2) thin films were conducted by putting them into the sealed quartz chamber of a home-made test equipment and recorded the current of sensing material in different atmospheres (details see ESI).[34] All tests were performed at RT.

NO_2 is one of the major global gas pollutants and very toxic even at low concentrations. The performances of NO_2 sensing materials were reported to be significantly enhanced by decorating the surface of them with –NH_2 contained molecules.[26,35] Inspired by this, few-layer Ag(SPh-NH_2) thin film is expected to show high RT sensing performances, because its surfaces are fully and orderly covered by –NH_2 groups which are effective "receptors" for NO_2. As shown in Fig. 3a, when exposed to 10 ppm NO_2, few-layer Ag(SPh-NH_2) thin film exhibited that its current dramatically increased and reached a saturation. After refilling the chamber with dry air, few-layer Ag(SPh-NH_2) recovered to its initial resistance. The response coefficient of variation (CV) is only 6.92% in five continuous cycles, which indicates excellent repeatability (Response values see Tab. S2). Few-layer Ag(SPh-NH_2) also showed good response-recovery ability to a broad concentration range of NO_2 (0.1-100 ppm) (Fig. 3a and Fig. S13). In addition, Ag(SPh-NH_2) thin film before and after NO_2 sensing tests show almost the same PXRD (Fig. S14), indicating it is stable in NO_2 atmosphere. Notably, compared with the reported 2D chemiresistive sensing

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DOI: 10.1039/D0CC01092H

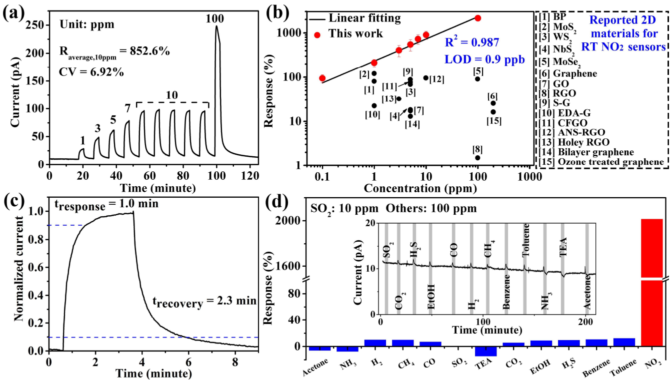

Fig. 3 (a) Response-recovery curve of Ag(SPh-NH$_2$) thin film to NO$_2$ with different concentrations at RT. (b) Linear log-log plot of response vs concentration of Ag(SPh-NH$_2$) thin film to NO$_2$ and their comparison with reported 2D chemiresistive sensing materials working at RT (details see Tab. S3). (c) Response-recovery curve to 10 ppm NO$_2$. (d) Cross-sensitivities of Ag(SPh-NH$_2$) thin film to 13 types of gases, inset is the real-time measurement (details see Tab. S4).

materials, few-layer Ag(SPh-NH$_2$) exhibits the highest response to NO$_2$ in whole above-mentioned concentration range (Fig. 3b and Tab. S3).

The response-concentration log-log plot of few-layer Ag(SPh-NH$_2$) is shown in Fig. 3b. The good linearity ($R^2 = 0.987$) in the range of 0.1-100 ppm is consistent with these of typical chemiresistive sensing materials.[34] Accordingly, the theoretical limit of detection (LOD) was calculated to be 0.9 ppb by setting R = 10%, which is the lowest value in all reported 2D chemiresistive sensing materials and good enough to achieve the detection of trace NO$_2$.[36] Few-layer Ag(SPh-NH$_2$) also showed fast response and recovery speed (Fig. 3c). The response and recovery time are calculated to be 1.0 and 2.3 minutes, respectively. These values suggest that few-layer Ag(SPh-NH$_2$) is the fastest 2D chemiresistive sensing material to NO$_2$ at RT reported so far (Tab. S3).

The organic "receptor" fully covered structure of few-layer Ag(SPh-NH$_2$) not only enhanced the sensitivity but also provided excellent selectivity to NO$_2$ (Fig. 3d). It showed very weak responses (< 20%) toward 12 commonly existed interference gases including SO$_2$, a typical interference gas for NO$_2$ detection (Response values see Tab. S4), indicating that few-layer Ag(SPh-NH$_2$) is capable to selectively distinguish NO$_2$ from its interference gases. To shed more light on the relationships between crystal structure and sensing performances, Ag(SPh), a p-type semiconducting isostructure of Ag(SPh-NH$_2$), was investigated (Fig. 1c, S15-17). However, different from Ag(SPh-NH$_2$), Ag(SPh) did not display any observable response to 10 ppm NO$_2$ (Fig. 4a). This result suggests that -NH$_2$ groups are crucial for detecting NO$_2$. To uncover more details, *in-situ* diffuse reflectance infrared Fourier transform spectroscopy (DRIFTS) measurements were performed by exposing Ag(SPh-NH$_2$) in NO$_2$ atmosphere to study the their interactions (Fig. 4b and Fig. S18). With the increasing exposure time, the intensity of the peaks for -NH$_2$ vibrations (3380 and 3301 cm^{-1}) and C-N (1251 cm^{-1}) stretching vibration decreased dramatically.[37] The peak at 3190 cm^{-1} decreased obviously can be assigned to the overtone of N-H bending vibration. Meanwhile, four new peaks belonging to NO$_2$ (1505 and 1318 cm^{-1}) and N$_2$O$_4$ (1496, 1319 cm^{-1} and 1287, 1224 cm^{-1}, the dimer of NO$_2$) were observed to increase their intensities with extending the exposure time.[38-39]

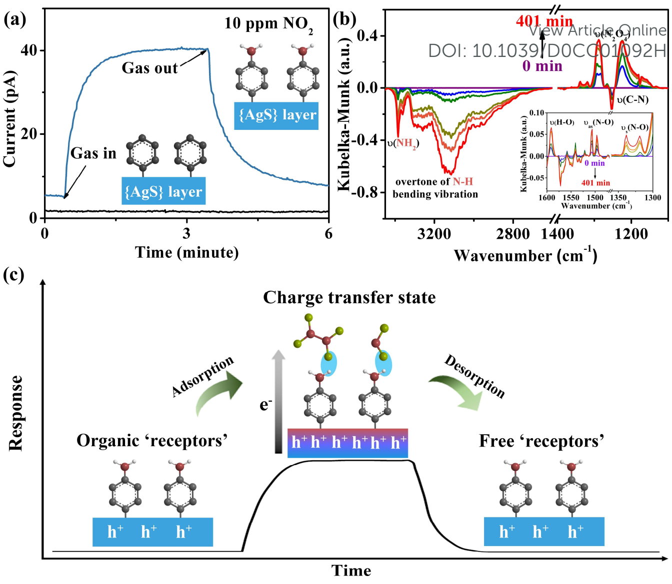

Fig. 4 (a) Response-recovery curves of Ag(SPh-NH$_2$) (blue) and Ag(SPh) (black) to 10 ppm NO$_2$. (b) *In-situ* DRIFT Spectra for Ag(SPh-NH$_2$) exposed to NO$_2$ as a function of time. (c) Possible NO$_2$ sensing mechanism for Ag(SPh-NH$_2$).

Compared with their gaseous state, the adsorbed NO$_2$ and N$_2$O$_4$ showed slight shift. Meanwhile, O-H bending vibration at 1591 cm^{-1} was also observed (Fig. 4b).[40] These observations revealed the formation of hydrogen bond through O atoms of N$_2$O$_4$ / NO$_2$ and H atoms of -NH$_2$ groups. During the above process, none of the peaks related to diazonium salt (2280 cm^{-1}) or nitrates (1350 cm^{-1}) was detected,[37-38] indicating a strong adsorption of NO$_2$ on Ag(SPh-NH$_2$). Notably, the intensity change of -NH$_2$ and N$_2$O$_4$ related peaks was synchronous, which revealed a strong interaction between -NH$_2$ and adsorbed N$_2$O$_4$. Above results demonstrated the critical role of –NH$_2$ groups as a functional motif played in Ag(SPh-NH$_2$) sensing material.[41-42]

A possible mechanism of NO$_2$ detection with Ag(SPh-NH$_2$) is proposed as following (Figure 4c): when NO$_2$ approaches the surface of Ag(SPh-NH$_2$), it firstly contacts with the –NH$_2$ groups through strong interaction (e.g. acid-based interaction, hydrogen bond)[43] in the form of NO$_2$ / N$_2$O$_4$; simultaneously, charge transfer from Ag(SPh-NH$_2$) to NO$_2$ and N$_2$O$_4$ would happen which increases the concentration of hole carriers for p-type Ag(SPh-NH$_2$); finally Ag(SPh-NH$_2$) shows a positive response by increasing its current; once NO$_2$ and N$_2$O$_4$ molecules are swept away by purging gases from the surface of Ag(SPh-NH$_2$), the current recovers to its initial value.

In conclusion, OMCs, a family of newly emerging inorganic 2D materials, were demonstrated as a kind of designable high-performance RT chemiresitive gas sensing materials for the first time. This was realized by preparing few-layer Ag(SPh-NH$_2$), a member of OMCs, and ap-plied it in NO$_2$ detection. Ag(SPh-NH$_2$) possesses a semi-conducting $\{AgS\}_n$ layer and –NH$_2$ groups fully and orderly covered surfaces. The comparison of the sensing performances between Ag(SPh-NH$_2$) and its isostructure, Ag(SPh), and *in-situ* DRIFTS measurements of Ag(SPh-NH$_2$) in NO$_2$ atmosphere revealed –NH$_2$ groups are effective "receptors" to interact with NO$_2$ and play the critical role in dramatically enhancing its sensing sensitivity and selectivity. As a result, it shows the highest response value, lowest LOD, and fastest response & recovery speed to NO_2 in all reported 2D chemiresistive sensing materials at RT. Moreover, it also shows excellent selectivity towards 12 commonly existed interference gases for NO_2 detection. Given that the organic function groups on OMCs can be flexibly designed for different gas detection purposes, our work should bring great inspiration in designing and producing the next generation of highly selective and sensitive sensing materials for RT operation.

This work was supported by the NSF of China (21822109, 21975254, 21805276, 21905280), Key Research Program of Frontier Science, CAS (QYZDB-SSWSLH023), the Strategic Priority Research Program of CAS (XDB20000000), International Partnership Program of CAS (121835KYSB201800), and Youth Innovation Promotion Association CAS.

Conflicts of interest

There are no conflicts to declare.

Notes and references

1 E. Comini, C. Baratto, G. Faglia, M. Ferroni, A. Vomiero and G. Sberveglieri, *Prog. Mater. Sci.,* 2009, **54**, 1.
2 S. Chen, Y. Tang, K. Zhan, D. Sun and X. Hou, *Nano Today,* 2018, **20**, 84.
3 Y. Liu, R. Bao, J. Tao, J. Li, M. Dong and C. Pan, *Sci. Bull.,* 2020, **60**, 70.
4 V. Dua, S. P. Surwade, S. Ammu, S. R. Agnihotra, S. Jain, K. E. Roberts, S. Park, R. S. Ruoff and S. K. Manohar, *Angew. Chem. Int. Ed.*, 2010, **49**, 2154.
5 E. Singh, M. Meyyappan and H. S. Nalwa, *ACS Appl. Mater. Inter.*, 2017, **9**, 34544.
6 J. Feng, L. Peng, C. Wu, X. Sun, S. Hu, C. Lin, J. Dai, J. Yang and Y. Xie, *Adv. Mater.*, 2012, **24**, 1969.
7 F. K. Perkins, A. L. Friedman, E. Cobas, P. M. Campbell, G. G. Jernigan and B. T. Jonker, *Nano Lett.,* 2013, **13**, 668.
8 W. Yuan, A. Liu, L. Huang, C. Li and G. Shi, *Adv. Mater.,* 2013, **25**, 766.
9 S. Y. Cho, Y. Lee, H. J. Koh, H. Jung, J. S. Kim, H. W. Yoo, J. Kim and H. T. Jung, *Adv. Mater.,* 2016, **28**, 7020.
10 S. Y. Cho, H. J. Koh, H. W. Yoo and H. T. Jung, *Chem. Mater.,* 2017, **29**, 7197.
11 M. G. Campbell, D. Sheberla, S. F. Liu, T. M. Swager and M. Dincă, *Angew. Chem. Int. Ed.,* 2015, **54**, 4349.
12 M. G. Campbell, S. F. Liu, T. M. Swager and M. Dincă, *J. Am. Chem. Soc.,* 2015, **137**, 13780.
13 M. K. Smith and K. A. Mirica, *J. Am. Chem. Soc.,* 2017, **139**, 16759.
14 Y. Ding, Y. P. Chen, X. Zhang, L. Chen, Z. Dong, H. L. Jiang, H. Xu and H. C. Zhou, *J. Am. Chem. Soc.,* 2017, **139**, 9136.
15 R. Dong, Z. Zhang, D. C. Tranca, S. Zhou, M. Wang, P. Adler, Z. Liao, F. Liu, Y. Sun, W. Shi, Z. Zhang, E. Zschech, S. C. B. Mannsfeld, C. Felser and X. Feng, *Nat. Commun.,* 2018, **9**, 2637.
16 M. Zhao, Y. Huang, Y. Peng, Z. Huang, Q. Ma and H. Zhang, *Chem. Soc. Rev.,* 2018, **47**, 6267.
17 M. S. Yao, J. J. Zheng, A. Q. Wu, G. Xu, S. S. Nagarkar, G. Zhang, M. Tsujimoto, S. Sakaki, S. Horike, K. Otake, and S. Kitagawa, *Angew. Chem. Int. Ed.*, 2020, **59**, 172.
18 W. T. Koo, J. S. Jang and I. D. Kim, *Chem,* 2019, **5**, 1938.
19 M. S. Yao, X. J. Lv, Z. H. Fu, W. H. Li, W. H. Deng, G. D. Wu and G. Xu, *Angew. Chem. Int. Ed.*, 2017, **56**, 16510.
20 M. S. Yao, J. W. Xiu, Q. Q. Huang, W. H. Li, W. W. Wu, A. Q. Wu, L. A. Cao, W. H. Deng, G. E. Wang, G. Xu, *Angew. Chem. Int. Ed.,* 2019, **58**, 14915.
21 Z. Meng, R. M. Stolz and K. A. Mirica, *J. Am. Chem. Soc.,* 2019, **141**, 11929.
22 S. J. Choi and I. D. Kim, *Electron. Mater. Lett.,* 2018, **14**, 221.
23 Z. Meng, R. M. Stolz, L. Mendecki and K. A. Mirica, *Chem. Rev.,* 2019, **119**, 478.s
24 F. Yavari, E. Castillo, H. Gullapalli, P. M. Ajayan and N. Koratkar, *App. Phy. Lett.*, 2012, **100**, 203120.
25 B. Cho, A. R. Kim, Y. Park, J. Yoon, Y. J. Lee, S. Lee, T. J. Yoo, C. G. Kang, B. H. Lee, H. C. Ko, D. H. Kim and M. G. Hahm, *ACS. Appl. Mater. Inter.,* 2015, **7**, 2952.
26 K. Lee, R. Gatensby, N. McEvoy, T. Hallam and G. S. Duesberg, *Adv. Mater.,* 2013, **25**, 6699.
27 J. S. Kim, H. W. Yoo, H. O. Choi and H. T. Jung, *Nano Lett.,* 2014, **14**, 5941.
28 Y. H. Kim, J. S. Park, Y. R. Choi, S. Y. Park, S. Y. Lee, W. Sohn, Y. S. Shim, J. H. Lee, C. R. Park, Y. S. Choi, B. H. Hong, J. H. Lee, W. H. Lee, D. Lee and H. W. Jang, *J. Mater. Chem. A,* 2017, **5**, 19116.
29 Y. Z. Li, J. Shu, Q. Q. Huang, K. Chiranjeevulu, P. N. Kumar, G. E. Wang, W. H. Deng, D. Tang and G. Xu, *Chem. Commun.,* 2019, **55**, 10444.
30 Y. Z. Li, X. M. Jiang, Z. H. Fu, Q. Q. Huang, G. E. Wang, W. H. Deng, C. Wang, Z. Z. Li, W. J. Yin, B. L. Chen and G. Xu, *Nat. Commun.*, 2020, **11**, 261.
31 L. G. Dance, K. J. Fisher, R. M. Herath Banda, M. L. Scudder, R. M. Herath Banda and M. L. Scudder, *Inorg. Chem.,* 1991, **30**, 183.
32 H. Yu, P. Xiao, J. Tian, F. Wang and J. Yu, *ACS Appl. Mater. Inter.,* 2016, **8**, 29470.
33 K. H. Low, V. A. Roy, S. S. Chui, S. L. Chan and C. M. Che, *Chem. Commun.,* 2010, **46**, 7328.
34 M. S. Yao, W. X. Tang, G. E. Wang, B. Nath and G. Xu, *Adv. Mater.,* 2016, **28**, 5229.
35 M. W. G. Hoffmann, J. D. Prades, L. Mayrhofer, F. Hernandez-Ramirez, T. T. Järvi, M. Moseler, A. Waag and H. Shen, *Adv. Funct. Mater.,* 2014, **24**, 595.
36 J. S. Kim, J. W. Yoon, Y. J. Hong, Y. C. Kang, F. Abdel-Hady, A. A. Wazzan and J. H. Lee, *Sens. Actuators B Chem.,* 2016, **229**, 561.
37 G. W. Peterson, J. J. Mahle, J. B. DeCoste, W. O. Gordon and J. A. Rossin, *Angew. Chem. Int. Ed.,* 2016, **55**, 6235.
38 E. Flores, J. Viallon, P. Moussay, F. Idrees and R. I. Wielgosz, *Anal. Chem.,* 2012, **84**, 10283.
39 C. Yu, H. Z. Lin, J. Zhou, X. F. Cheng, J. H. He, H. Li, Q. F. Xu, N. J. Li, D. Y. Chen and J. M. Lu, *J. Mater. Chem. A,* 2020, **8**, 1052.
40 B. Tyagi, C. D. Chudasama and R. V. Jasra, *Spectrochimica Acta Part A,* 2006, **64**, 273.
41 G. C. Guo, Y. G. Yao, K. C. Wu, L. Wu and J. S. Huang, *Prog. Chem.,* 2001, **13**, 151.
42 S.P. Guo, Y. Chi and G. C. Guo, *Coord. Chem. Rev.,* 2017, **335**, 44.
43 G. W. Peterson, M. McEntee, C. R. Harris, A. D. Klevitch, A. W. Fountain, J. R. Soliz, A. Balboa and A. J. Hauser, *Dalton. Trans.,* 2016, **45**, 17113.

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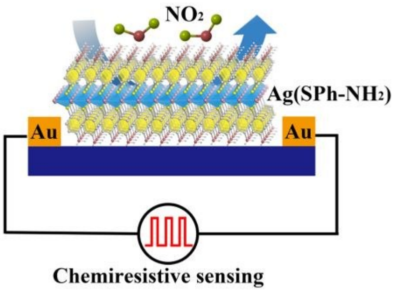

2D organic-metal chalcogenides (OMCs), were developed as a new type of materials for high-performance RT gas sensing.