

## References

- 1 Ehrenfreund, P., Irvine, W., Becker, L., Blank, J., Brucato, J.R., Colangeli, L., Derenne, S., Despois, D., Dutrey, A., Fraaije, H., Lazcano, A., Owen, T., Robert, F., ISSI-Team, A.I.S.S.I. Astrophysical and astrochemical insights into the origin of life. *Rep. Prog. Phys.* 2002, 65 (10): 1427–1487.
- 2 Novoselov, K.S., Geim, A.K., Morozov, S.V., Jiang, D., Zhang, Y., Dubonos, S.V., Grigorieva, I.V., Firsov, A.A. Electric field effect in atomically thin carbon films. *Science* 2004, 306 (5696): 666–669.
- 3 Li, X., Wang, X., Zhang, L., Lee, S., Dai, H. Chemically derived, ultrasmooth graphene nanoribbon semiconductors. *Science* 2008, 319 (5867): 1229–1232.
- 4 Iijima, S. Helical microtubules of graphitic carbon. *Nature* 1991, 354 (6348): 56–58.
- 5 Li, G., Li, Y., Liu, H., Guo, Y., Li, Y., Zhu, D. Architecture of graphdiyne nanoscale films. *Chem. Commun.* 2010, 46 (19): 3256.
- 6 Kroto, H.W., Heath, J.R., O'Brien, S.C., Curl, R.F., Smalley, R.E. C<sub>60</sub>: Buckminsterfullerene. *Nature* 1985, 318 (6042): 162–163.
- 7 Xu, X., Ray, R., Gu, Y., Ploehn, H.J., Gearheart, L., Raker, K., Scrivens, W.A. Electrophoretic analysis and purification of fluorescent single-walled carbon nanotube fragments. *J. Am. Chem. Soc.* 2004, 126 (40): 12736–12737.
- 8 Geim, A.K., Novoselov, K.S. The rise of graphene. *Nat. Mater.* 2007, 6 (3): 183–191.
- 9 Landau, L.D. Zur Theorie Der Phasenumwandlungen II. *Phys. Z Sowjetunion* 1937, 11 (545): 26–35.
- 10 Peierls, R. Quelques Propriétés Typiques Des corps solides. In: *Annales de l'institut Henri Poincaré* 1935, 5: 177–222.
- 11 Land, T., Michely, T., Behm, R., Hemminger, J., Comsa, G. STM investigation of single layer graphite structures produced on Pt (111) by hydrocarbon decomposition. *Surf. Sci.* 1992, 264 (3): 261–270.
- 12 Dresselhaus, M.S., Dresselhaus, G. Intercalation compounds of graphite. *Adv. Phys.* 2002, 51 (1): 1–186.
- 13 Wang, X.-Y., Narita, A., Müllen, K. Precision synthesis versus bulk-scale fabrication of graphenes. *Nat. Rev. Chem.* 2017, 2 (1): 0100.
- 14 Moon, J.-Y., Kim, M., Kim, S.-I., Xu, S., Choi, J.-H., Whang, D., Watanabe, K., Taniguchi, T., Park, D.S., Seo, J., Cho, S.H., Son, S.-K., Lee, J.-H. Layer-engineered large-area exfoliation of graphene. *Sci. Adv.* 2020, 6 (44): eabc6601.
- 15 Shim, J., Bae, S.-H., Kong, W., Lee, D., Qiao, K., Nezich, D., Park, Y.J., Zhao, R., Sundaram, S., Li, X., Yeon, H., Choi, C., Kum, H., Yue, R., Zhou, G., Ou, Y., Lee, K., Moodera, J., Zhao, X., Ahn, J.-H., Hinkle, C., Ougazzaden, A., Kim, J. Controlled crack propagation for atomic precision handling of wafer-scale two-dimensional materials. *Science* 2018, 362 (6415): 665–670.
- 16 Ming-Yuan, H., Hutchinson, J.W. Crack deflection at an interface between dissimilar elastic materials. *Int. J. Solids Struct.* 1989, 25 (9): 1053–1067.
- 17 Huang, Y., Pan, Y.-H., Yang, R., Bao, L.-H., Meng, L., Luo, H.-L., Cai, Y.-Q., Liu, G.-D., Zhao, W.-J., Zhou, Z., Wu, L.-M., Zhu, Z.-L., Huang, M., Liu, L.-W., Liu, L., Cheng, P., Wu, K.-H., Tian, S.-B., Gu, C.-Z., Shi, Y.-G., Guo, Y.-F., Cheng, Z.G., Hu, J.-P., Zhao, L.,

- Yang, G.-H., Sutter, E., Sutter, P., Wang, Y.-L., Ji, W., Zhou, X.-J., Gao, H.-J. Universal mechanical exfoliation of large-area 2D crystals. *Nat. Commun.* 2020, 11 (1): 2453.
- 18 Hernandez, Y., Nicolosi, V., Lotya, M., Blighe, F.M., Sun, Z., De, S., McGovern, I.T., Holland, B., Byrne, M., Gun'Ko, Y.K., Boland, J.J., Niraj, P., Duesberg, G., Krishnamurthy, S., Goodhue, R., Hutchison, J., Scardaci, V., Ferrari, A.C., Coleman, J.N. High-yield production of graphene by liquid-phase exfoliation of graphite. *Nat. Nanotechnol.* 2008, 3 (9): 563–568.
  - 19 León, V., Rodríguez, A.M., Prieto, P., Prato, M., Vázquez, E. Exfoliation of graphite with triazine derivatives under ball-milling conditions: preparation of few-layer graphene via selective noncovalent interactions. *ACS Nano* 2014, 8 (1): 563–571.
  - 20 Paton, K.R., Varrla, E., Backes, C., Smith, R.J., Khan, U., O'Neill, A., Boland, C., Lotya, M., Istrate, O.M., King, P., Higgins, T., Barwich, S., May, P., Puczkarski, P., Ahmed, I., Moebius, M., Pettersson, H., Long, E., Coelho, J., O'Brien, S.E., McGuire, E.K., Sanchez, B.M., Duesberg, G.S., McEvoy, N., Pennycook, T.J., Downing, C., Crossley, A., Nicolosi, V., Coleman, J.N. Scalable production of large quantities of defect-free few-layer graphene by shear exfoliation in liquids. *Nat. Mater.* 2014, 13 (6): 624–630.
  - 21 Ciesielski, A., Samorì, P. Graphene via sonication assisted liquid-phase exfoliation. *Chem. Soc. Rev.* 2014, 43 (1): 381–398.
  - 22 Liu, W., Zheng, X., Xu, Q. Supercritical CO<sub>2</sub> directional-assisted synthesis of low-dimensional materials for functional applications. *Small* 2023, 19 (33): 2301097.
  - 23 Romang, A.H., Watkins, J.J. Supercritical fluids for the fabrication of semiconductor devices: emerging or missed opportunities? *Chem. Rev.* 2010, 110 (1): 459–478.
  - 24 Jones, C.A., Zweber, A., DeYoung, J.P., McClain, J.B., Carbonell, R., DeSimone, J.M. Applications of “dry” processing in the microelectronics industry using carbon dioxide. *Crit. Rev. Solid State Mater. Sci.* 2004, 29 (3–4): 97–109.
  - 25 Zhu, H.-Y., Wang, Q.-B., Yin, J.-Z. High-pressure induced exfoliation for regulating the morphology of graphene in supercritical CO<sub>2</sub> system. *Carbon* 2021, 178: 211–222.
  - 26 Zhao, M., Casiraghi, C., Parvez, K. Electrochemical exfoliation of 2D materials beyond graphene. *Chem. Soc. Rev.* 2024, 53 (6): 3036–3064.
  - 27 Lee, H., Jin, S., Chung, J., Kim, M., Lee, S.W. Electrochemical production of two-dimensional atomic layer materials and their application for energy storage devices. *Chem. Phys. Rev.* 2023, 4 (1): 011306.
  - 28 Mirkhani, S.A., Iqbal, A., Kwon, T., Chae, A., Kim, D., Kim, H., Kim, S.J., Kim, M.-K., Koo, C.M. Reduction of electrochemically exfoliated graphene films for high-performance electromagnetic interference shielding. *ACS Appl. Mater. Interfaces* 2021, 13 (13): 15827–15836.
  - 29 Wang, S., Xue, J., Xu, D., He, J., Dai, Y., Xia, T., Huang, Y., He, Q., Duan, X., Lin, Z. Electrochemical molecular intercalation and exfoliation of solution-processable two-dimensional crystals. *Nat. Protoc.* 2023, 18 (9): 2814–2837.
  - 30 Yang, S., Zhang, P., Nia, A.S., Feng, X. Emerging 2D materials produced via electrochemistry. *Adv. Mater.* 2020, 32 (10): 1907857.
  - 31 Lu, X., Cai, M., Wu, X., Zhang, Y., Li, S., Liao, S., Lu, X. Controllable synthesis of 2D materials by electrochemical exfoliation for energy storage and conversion application. *Small* 2023, 19 (9): 2206702.
  - 32 Brodie, B.C. Sur Le Poids Atomique Du Graphite. *Ann. Chim. Phys.* 1860, 59: 466–472.

- 33 Staudenmaier, L. Verfahren Zur Darstellung Der Graphitsäure. *Berichte Dtsch. Chem. Ges.* 1898, 31 (2): 1481–1487.
- 34 Hummers, W.S., Offeman, R.E. Preparation of graphitic oxide. *J. Am. Chem. Soc.* 1958, 80 (6): 1339–1339.
- 35 Zelenák, F., Kováčová, M., Moravec, Z., Černák, M., Krumpolec, R. Fast, scalable, and environmentally friendly method for production of stand-alone ultrathin reduced graphene oxide paper. *Carbon* 2023, 215: 118436.
- 36 Tao, R., Li, F., Lu, X., Liu, F., Xu, J., Kong, D., Zhang, C., Tan, X., Ma, S., Shi, W., Mo, R., Lu, Y. High-conductivity–dispersibility graphene made by catalytic exfoliation of graphite for lithium-ion battery. *Adv. Funct. Mater.* 2021, 31 (6): 2007630.
- 37 Van Bommel, A.J., Crombeen, J.E., Van Tooren, A. LEED and auger electron observations of the SiC (0001) surface. *Surf. Sci.* 1975, 48 (2): 463–472.
- 38 Forbeaux, I., Themlin, J.-M., Debever, J.-M. Heteroepitaxial graphite on 6 H – SiC (0001): interface formation through conduction-band electronic structure. *Phys. Rev. B* 1998, 58 (24): 16396–16406.
- 39 Zhao, J., Ji, P., Li, Y., Li, R., Zhang, K., Tian, H., Yu, K., Bian, B., Hao, L., Xiao, X., Griffin, W., Dudeck, N., Moro, R., Ma, L., De Heer, W.A. Ultrahigh-mobility semiconducting epitaxial graphene on silicon carbide. *Nature* 2024, 625 (7993): 60–65.
- 40 De Heer, W.A., Berger, C., Ruan, M., Sprinkle, M., Li, X., Hu, Y., Zhang, B., Hankinson, J., Conrad, E. Large area and structured epitaxial graphene produced by confinement controlled sublimation of silicon carbide. *Proc. Natl. Acad. Sci.* 2011, 108 (41): 16900–16905.
- 41 Bao, J., Yasui, O., Norimatsu, W., Matsuda, K., Kusunoki, M. Sequential control of step-bunching during graphene growth on SiC (0001). *Appl. Phys. Lett.* 2016, 109 (8): 081602.
- 42 Sun, Z., Yan, Z., Yao, J., Beitler, E., Zhu, Y., Tour, J.M. Growth of graphene from solid carbon sources. *Nature* 2010, 468 (7323): 549–552.
- 43 Qi, T., Shao, Q., Qi, H., Xiao, J., Zhang, Y., Wang, Y., Jin, X., Chen, Y., Li, D., Zang, X., Cao, N. CVD growth of graphene on copper-plated scrap steel without external carbon source. *Nano Res.* 2023, 16 (10): 12263–12269.
- 44 Yi, X., Song, Q., Chen, Q., Zhao, C., Watanabe, K., Taniguchi, T., Chen, Q., Yan, C., Wang, S. Quantum transport in CVD graphene synthesized with liquid carbon precursor. *Nanotechnology* 2022, 33 (35): 355601.
- 45 Yu, Q., Lian, J., Siriponglert, S., Li, H., Chen, Y.P., Pei, S.-S. Graphene segregated on Ni surfaces and transferred to insulators. *Appl. Phys. Lett.* 2008, 93 (11): 113103.
- 46 Kim, K.S., Zhao, Y., Jang, H., Lee, S.Y., Kim, J.M., Kim, K.S., Ahn, J.-H., Kim, P., Choi, J.-Y., Hong, B.H. Large-scale pattern growth of graphene films for stretchable transparent electrodes. *Nature* 2009, 457 (7230): 706–710.
- 47 Li, X., Cai, W., An, J., Kim, S., Nah, J., Yang, D., Piner, R., Velamakanni, A., Jung, I., Tutuc, E., Banerjee, S.K., Colombo, L., Ruoff, R.S. Large-area synthesis of high-quality and uniform graphene films on copper foils. *Science* 2009, 324 (5932): 1312–1314.
- 48 Zhang, J., Liu, X., Zhang, M., Zhang, R., Ta, H.Q., Sun, J., Wang, W., Zhu, W., Fang, T., Jia, K., Sun, X., Zhang, X., Zhu, Y., Shao, J., Liu, Y., Gao, X., Yang, Q., Sun, L., Li, Q., Liang, F., Chen, H., Zheng, L., Wang, F., Yin, W., Wei, X., Yin, J., Gemming, T., Rummeli, M.H., Liu, H., Peng, H., Lin, L., Liu, Z. Fast synthesis of large-area bilayer graphene film on Cu. *Nat. Commun.* 2023, 14 (1): 3199.

- 49 Saito, R., Fujita, M., Dresselhaus, G., Dresselhaus, M.S. Electronic structure of chiral graphene tubules. *Appl. Phys. Lett.* 1992, 60 (18): 2204–2206.
- 50 Muhulet, A., Miculescu, F., Voicu, S.I., Schütt, F., Thakur, V.K., Mishra, Y.K. Fundamentals and scopes of doped carbon nanotubes towards energy and biosensing applications. *Mater. Today Energy* 2018, 9: 154–186.
- 51 Venkataraman, A., Amadi, E.V., Chen, Y., Papadopoulos, C. Carbon nanotube assembly and integration for applications. *Nanoscale Res. Lett.* 2019, 14 (1): 220.
- 52 Dresselhaus, M.S., Dresselhaus, G., Saito, R. Physics of carbon nanotubes. *Carbon* 1995, 33 (7): 883–891.
- 53 Liu, Y., Ge, Z., Li, Z., Chen, Y. High-power instant-synthesis technology of carbon nanomaterials and nanocomposites. *Nano Energy* 2021, 80: 105500.
- 54 Zain Mehdi, S.M., Shin, T.H., Abbas, S.Z., Kwon, H., Seo, Y., Kim, D., Hong, S.J., Goak, J.C., Lee, N. Superior field emission characteristics of highly crystalline and thermally stable carbon nanotubes grown in N<sub>2</sub> and O<sub>2</sub> by arc discharge. *Ceram. Int.* 2023, 49 (3): 4668–4676.
- 55 Ribeiro, H., Schnitzler, M.C., Da Silva, W.M., Santos, A.P. Purification of carbon nanotubes produced by the electric arc-discharge method. *Surf. Interfaces* 2021, 26: 101389.
- 56 Guo, T., Nikolaev, P., Thess, A., Colbert, D.T., Smalley, R.E. Catalytic growth of single-walled nanotubes by laser vaporization. *Chem. Phys. Lett.* 1995, 243 (1–2): 49–54.
- 57 Chen, S., Chen, Y., Xu, H., Lyu, M., Zhang, X., Han, Z., Liu, H., Yao, Y., Xu, C., Sheng, J., Xu, Y., Gao, L., Gao, N., Zhang, Z., Peng, L., Li, Y. Single-walled carbon nanotubes synthesized by laser ablation from coal for field-effect transistors. *Mater. Horiz.* 2023, 10 (11): 5185–5191.
- 58 Qin, X., Li, Y., Chernov, A.I., He, M., Zhao, W., Gao, Y., Li, Y., Qiu, S., Li, Q. Towards the preparation of single-walled carbon nanotubes with average diameter of 1.2 nm. *Carbon* 2024, 224: 119059.
- 59 Li, Y., Kim, W., Zhang, Y., Rolandi, M., Wang, D., Dai, H. Growth of single-walled carbon nanotubes from discrete catalytic nanoparticles of various sizes. *J. Phys. Chem. B* 2001, 105 (46): 11424–11431.
- 60 Zheng, J., Yang, R., Xie, L., Qu, J., Liu, Y., Li, X. Plasma-assisted approaches in inorganic nanostructure fabrication. *Adv. Mater.* 2010, 22 (13): 1451–1473.
- 61 Huang, S., Woodson, M., Smalley, R., Liu, J. Growth mechanism of oriented long single walled carbon nanotubes using “fast-heating” chemical vapor deposition process. *Nano Lett.* 2004, 4 (6): 1025–1028.
- 62 Zhu, Z., Cui, C., Bai, Y., Gao, J., Jiang, Y., Li, B., Wang, Y., Zhang, Q., Qian, W., Wei, F. Advances in precise structure control and assembly toward the carbon nanotube industry. *Adv. Funct. Mater.* 2022, 32 (11): 2109401.
- 63 Liu, F., Yuan, M., He, Y., Zhai, G., Xiang, H., Wu, Q., Zhu, M. Insights into the nucleation and structure of lignin-based carbon nanotubes synthesized using iron via floating catalyst chemical vapor deposition. *ACS Appl. Nano Mater.* 2024, 7 (7): 7184–7194.
- 64 Xu, Y., Miao, X., Chen, H., Gu, X., Liu, Y., Ma, C., Zhang, X., Zou, J. Fe complex-based catalyst system for the chirality-selected continuous synthesis of single-walled carbon nanotubes. *ACS Appl. Nano Mater.* 2024, 7 (5): 5525–5533.

- 65 Hou, P., Zhang, F., Zhang, L., Liu, C., Cheng, H. Synthesis of carbon nanotubes by floating catalyst chemical vapor deposition and their applications. *Adv. Funct. Mater.* 2022, 32 (11): 2108541.
- 66 Jiang, Q., Wang, F., Li, R., Li, B., Wei, N., Gao, N., Xu, H., Zhao, S., Huang, Y., Wang, B., Zhang, W., Wu, X., Zhang, S., Zhao, Y., Shi, E., Zhang, R. Synthesis of ultralong carbon nanotubes with ultrahigh yields. *Nano Lett.* 2023, 23 (2): 523–532.
- 67 Zhang, R., Zhang, Y., Zhang, Q., Xie, H., Qian, W., Wei, F. Growth of half-meter long carbon nanotubes based on Schulz–Flory distribution. *ACS Nano* 2013, 7 (7): 6156–6161.
- 68 Baughman, R.H., Eckhardt, H., Kertesz, M. Structure-property predictions for new planar forms of carbon: layered phases containing  $sp^2$  and  $sp$  atoms. *J. Chem. Phys.* 1987, 87 (11): 6687–6699.
- 69 Zheng, X., Chen, S., Li, J., Wu, H., Zhang, C., Zhang, D., Chen, X., Gao, Y., He, F., Hui, L., Liu, H., Jiu, T., Wang, N., Li, G., Xu, J., Xue, Y., Huang, C., Chen, C., Guo, Y., Lu, T.-B., Wang, D., Mao, L., Zhang, J., Zhang, Y., Chi, L., Guo, W., Bu, X.-H., Zhang, H., Dai, L., Zhao, Y., Li, Y. Two-dimensional carbon graphdiyne: advances in fundamental and application research. *ACS Nano* 2023, 17 (15): 14309–14346.
- 70 Li, H., Lim, J.H., Lv, Y., Li, N., Kang, B., Lee, J.Y. Graphynes and graphdienes for energy storage and catalytic utilization: theoretical insights into recent advances. *Chem. Rev.* 2023, 123 (8): 4795–4854.
- 71 Hu, G., He, J., Chen, J., Li, Y. Synthesis of a wheel-shaped nanographdiyne. *J. Am. Chem. Soc.* 2023, 145 (9): 5400–5409.
- 72 Zhou, J., Gao, X., Liu, R., Xie, Z., Yang, J., Zhang, S., Zhang, G., Liu, H., Li, Y., Zhang, J., Liu, Z. Synthesis of graphdiyne nanowalls using acetylenic coupling reaction. *J. Am. Chem. Soc.* 2015, 137 (24): 7596–7599.
- 73 Li, C., Lu, X., Han, Y., Tang, S., Ding, Y., Liu, R., Bao, H., Li, Y., Luo, J., Lu, T. Direct imaging and determination of the crystal structure of six-layered graphdiyne. *Nano Res.* 2018, 11 (3): 1714–1721.
- 74 Matsuoka, R., Sakamoto, R., Hoshiko, K., Sasaki, S., Masunaga, H., Nagashio, K., Nishihara, H. Crystalline graphdiyne nanosheets produced at a gas/liquid or liquid/liquid interface. *J. Am. Chem. Soc.* 2017, 139 (8): 3145–3152.
- 75 Xu, L., Sun, J., Tang, T., Zhang, H., Sun, M., Zhang, J., Li, J., Huang, B., Wang, Z., Xie, Z., Wong, W. Metallated graphynes as a new class of photofunctional 2D organometallic nanosheets. *Angew. Chem. Int. Ed.* 2021, 60 (20): 11326–11334.
- 76 Huang, R., Kou, Z., Rodriguez, R.D., Wang, X., Hou, Y., Wang, T., Zhang, T. Two-dimensional silver-metalated graphdiyne nanosheets for photocatalytic degradation of antibiotics. *ACS Appl. Nano Mater.* 2023, 6 (9): 7395–7403.
- 77 He, S., Wu, B., Xia, Z., Guo, P., Li, Y., Song, S. One-pot synthesis of gamma-graphyne supported pd nanoparticles with high catalytic activity. *Nanoscale Adv.* 2023, 5 (9): 2487–2492.
- 78 Li, J., Cao, H., Wang, Q., Zhang, H., Liu, Q., Chen, C., Shi, Z., Li, G., Kong, Y., Cai, Y., Shen, J., Wu, Y., Lai, Z., Han, Y., Zhang, J. Space-confined synthesis of monolayer graphdiyne in MXene interlayer. *Adv. Mater.* 2024, 36 (7): 2308429.
- 79 Yan, H., Yu, P., Han, G., Zhang, Q., Gu, L., Yi, Y., Liu, H., Li, Y., Mao, L. High-yield and damage-free exfoliation of layered graphdiyne in aqueous phase. *Angew. Chem. Int. Ed.* 2019, 58 (3): 746–750.

- 80 Liu, R., Gao, X., Zhou, J., Xu, H., Li, Z., Zhang, S., Xie, Z., Zhang, J., Liu, Z. Chemical vapor deposition growth of linked carbon monolayers with acetylenic scaffoldings on silver foil. *Adv. Mater.* 2017, 29 (18): 1604665.
- 81 Li, Q., Li, Y., Chen, Y., Wu, L., Yang, C., Cui, X. Synthesis of  $\gamma$ -graphyne by mechanochemistry and its electronic structure. *Carbon* 2018, 136: 248–254.
- 82 Lee, J., Li, Y., Tang, J., Cui, X. Synthesis of hydrogen substituted graphyne through mechanochemistry and its electrocatalytic properties. *Acta Phys.-Chim. Sin.* 2018, 34 (9): 1080–1087.
- 83 Fitzer, E., Kochling, K.-H., Boehm, H.P., Marsh, H. Recommended terminology for the description of carbon as a solid (IUPAC Recommendations 1995). *Pure Appl. Chem.* 1995, 67 (3): 473–506.
- 84 Boehm, H. Graphene—How a laboratory curiosity suddenly became extremely interesting. *Angew. Chem. Int. Ed.* 2010, 49 (49): 9332–9335.
- 85 Partoens, B., Peeters, F.M. From graphene to graphite: electronic structure around the K point. *Phys. Rev. B* 2006, 74 (7): 075404.
- 86 Wallace, P.R. The band theory of graphite. *Phys. Rev.* 1947, 71 (9): 622–634.
- 87 Castro Neto, A.H., Guinea, F., Peres, N.M.R., Novoselov, K.S., Geim, A.K. The electronic properties of graphene. *Rev. Mod. Phys.* 2009, 81 (1): 109–162.
- 88 Morozov, S.V., Novoselov, K.S., Katsnelson, M.I., Schedin, F., Elias, D.C., Jaszczak, J.A., Geim, A.K. Giant intrinsic carrier mobilities in graphene and its bilayer. *Phys. Rev. Lett.* 2008, 100 (1): 016602.
- 89 Zheng, Y., Sen, D., Das, S., Das, S. Graphene strain-effect transistor with colossal ON/OFF current ratio enabled by reversible nanocrack formation in metal electrodes on piezoelectric substrates. *Nano Lett.* 2023, 23 (7): 2536–2543.
- 90 Bai, Z., Xiao, Y., Luo, Q., Li, M., Peng, G., Zhu, Z., Luo, F., Zhu, M., Qin, S., Novoselov, K. Highly tunable carrier tunneling in vertical graphene- $\text{WS}_2$ -graphene van Der Waals heterostructures. *ACS Nano* 2022, 16 (5): 7880–7889.
- 91 Novoselov, K.S., Mishchenko, A., Carvalho, A., Castro Neto, A.H. 2D Materials and van Der Waals heterostructures. *Science* 2016, 353 (6298): aac9439.
- 92 Braga, D., Gutiérrez Lezama, I., Berger, H., Morpurgo, A.F. Quantitative determination of the band gap of  $\text{WS}_2$  with ambipolar ionic liquid-gated transistors. *Nano Lett.* 2012, 12 (10): 5218–5223.
- 93 Li, S., Li, J., Wang, Y., Yu, C., Li, Y., Duan, W., Wang, Y., Zhang, J. Large transport gap modulation in graphene via electric-field-controlled reversible hydrogenation. *Nat. Electron.* 2021, 4 (4): 254–260.
- 94 Chen, X., Shehzad, K., Gao, L., Long, M., Guo, H., Qin, S., Wang, X., Wang, F., Shi, Y., Hu, W., Xu, Y., Wang, X. Graphene hybrid structures for integrated and flexible optoelectronics. *Adv. Mater.* 2020, 32 (27): 1902039.
- 95 Koepfli, S.M., Baumann, M., Koyaz, Y., Gadola, R., Güngör, A., Keller, K., Horst, Y., Nashashibi, S., Schwanninger, R., Doderer, M., Passerini, E., Fedoryshyn, Y., Leuthold, J. Metamaterial graphene photodetector with bandwidth exceeding 500 Gigahertz. *Science* 2023, 380 (6650): 1169–1174.
- 96 Landy, N.I., Sajuyigbe, S., Mock, J.J., Smith, D.R., Padilla, W.J. Perfect metamaterial absorber. *Phys. Rev. Lett.* 2008, 100 (20): 207402.



- 97 Xia, F., Mueller, T., Lin, Y., Valdes-Garcia, A., Avouris, P. Ultrafast graphene photodetector. *Nat. Nanotechnol.* 2009, 4 (12): 839–843.
- 98 Sagade, A.A., Neumaier, D., Schall, D., Otto, M., Pesquera, A., Centeno, A., Elorza, A. Z., Kurz, H. Highly air stable passivation of graphene based field effect devices. *Nanoscale* 2015, 7 (8): 3558–3564.
- 99 Tian, P., Tang, L., Teng, K.S., Xiang, J., Lau, S.P. Recent advances in graphene homogeneous p–n junction for optoelectronics. *Adv. Mater. Technol.* 2019, 4 (7): 1900007.
- 100 Mylnikov, D.A., Titova, E.I., Kashchenko, M.A., Safonov, I.V., Zhukov, S.S., Semkin, V.A., Novoselov, K.S., Bandurin, D.A., Svintsov, D.A. Terahertz photoconductivity in bilayer graphene transistors: evidence for tunneling at gate-induced junctions. *Nano Lett.* 2023, 23 (1): 220–226.
- 101 Titova, E., Mylnikov, D., Kashchenko, M., Safonov, I., Zhukov, S., Dzhikirba, K., Novoselov, K.S., Bandurin, D.A., Alymov, G., Svintsov, D. Ultralow-noise terahertz detection by p–n junctions in gapped bilayer graphene. *ACS Nano* 2023, 17 (9): 8223–8232.
- 102 Gayduchenko, I., Xu, S.G., Alymov, G., Moskotin, M., Tretyakov, I., Taniguchi, T., Watanabe, K., Goltsman, G., Geim, A.K., Fedorov, G., Svintsov, D., Bandurin, D.A. Tunnel field-effect transistors for sensitive terahertz detection. *Nat. Commun.* 2021, 12 (1): 543.
- 103 Icking, E., Banszerus, L., Wörtche, F., Volmer, F., Schmidt, P., Steiner, C., Engels, S., Hesselmann, J., Goldsche, M., Watanabe, K., Taniguchi, T., Volk, C., Beschoten, B., Stampfer, C. Transport spectroscopy of ultraclean tunable band gaps in bilayer graphene. *Adv. Electron. Mater.* 2022, 8 (11): 2200510.
- 104 Brihuega, I., Mallet, P., González-Herrero, H., Trambly De Laissardiére, G., Ugeda, M.M., Magaud, L., Gómez-Rodríguez, J.M., Ynduráin, F., Veuillen, J.-Y. Unraveling the intrinsic and robust nature of van Hove singularities in twisted bilayer graphene by scanning tunneling microscopy and theoretical analysis. *Phys. Rev. Lett.* 2012, 109 (19): 196802.
- 105 Jain, S.K., Juričić, V., Barkema, G.T. Structure of twisted and buckled bilayer graphene. *2D Mater.* 2016, 4 (1): 015018.
- 106 Wu, Q., Qian, J., Wang, Y., Xing, L., Wei, Z., Gao, X., Li, Y., Liu, Z., Liu, H., Shu, H., Yin, J., Wang, X., Peng, H. Waveguide-integrated twisted bilayer graphene photodetectors. *Nat. Commun.* 2024, 15 (1): 3688.
- 107 Novoselov, K.S., Geim, A.K., Morozov, S.V., Jiang, D., Katsnelson, M.I., Grigorieva, I.V., Dubonos, S.V., Firsov, A.A. Two-dimensional gas of massless Dirac fermions in graphene. *Nature* 2005, 438 (7065): 197–200.
- 108 Zhang, G., Wu, H., Yang, L., Jin, W., Zhang, W., Chang, H. Graphene-based spintronics. *Appl. Phys. Rev.* 2024, 11 (2): 021308.
- 109 Sha, Y., Zheng, J., Liu, K., Du, H., Watanabe, K., Taniguchi, T., Jia, J., Shi, Z., Zhong, R., Chen, G. Observation of a Chern insulator in crystalline ABCA-tetralayer graphene with spin-orbit coupling. *Science* 2024, 384 (6694): 414–419.
- 110 Cao, Y., Fatemi, V., Demir, A., Fang, S., Tomarken, S.L., Luo, J.Y., Sanchez-Yamagishi, J.D., Watanabe, K., Taniguchi, T., Kaxiras, E., Ashoori, R.C., Jarillo-Herrero, P. Correlated insulator behaviour at half-filling in magic-angle graphene superlattices. *Nature* 2018, 556 (7699): 80–84.

- 111 Cao, Y., Fatemi, V., Fang, S., Watanabe, K., Taniguchi, T., Kaxiras, E., Jarillo-Herrero, P. Unconventional superconductivity in magic-angle graphene superlattices. *Nature* 2018, 556 (7699): 43–50.
- 112 Bistritzer, R., MacDonald, A.H. Moiré bands in twisted double-layer graphene. *Proc. Natl. Acad. Sci.* 2011, 108 (30): 12233–12237.
- 113 Chen, G., Sharpe, A.L., Gallagher, P., Rosen, I.T., Fox, E.J., Jiang, L., Lyu, B., Li, H., Watanabe, K., Taniguchi, T., Jung, J., Shi, Z., Goldhaber-Gordon, D., Zhang, Y., Wang, F. Signatures of tunable superconductivity in a trilayer graphene Moiré superlattice. *Nature* 2019, 572 (7768): 215–219.
- 114 Klein, D.R., Xia, L.-Q., MacNeill, D., Watanabe, K., Taniguchi, T., Jarillo-Herrero, P. Electrical switching of a bistable Moiré superconductor. *Nat. Nanotechnol.* 2023, 18 (4): 331–335.
- 115 Zheng, Z., Ma, Q., Bi, Z., De La Barrera, S., Liu, M.-H., Mao, N., Zhang, Y., Kiper, N., Watanabe, K., Taniguchi, T., Kong, J., Tisdale, W.A., Ashoori, R., Gedik, N., Fu, L., Xu, S.-Y., Jarillo-Herrero, P. Unconventional ferroelectricity in Moiré heterostructures. *Nature* 2020, 588 (7836): 71–76.
- 116 Tang, D.-M., Cretu, O., Ishihara, S., Zheng, Y., Otsuka, K., Xiang, R., Maruyama, S., Cheng, H.-M., Liu, C., Golberg, D. Chirality engineering for carbon nanotube electronics. *Nat. Rev. Electr. Eng.* 2024, 1 (3): 149–162.
- 117 Samsonidze, G.G., Saito, R., Kobayashi, N., Grüneis, A., Jiang, J., Jorio, A., Chou, S.G., Dresselhaus, G., Dresselhaus, M.S. Family behavior of the optical transition energies in single-wall carbon nanotubes of smaller diameters. *Appl. Phys. Lett.* 2004, 85 (23): 5703–5705.
- 118 Su, W., Li, X., Li, L., Yang, D., Wang, F., Wei, X., Zhou, W., Kataura, H., Xie, S., Liu, H. Chirality-dependent electrical transport properties of carbon nanotubes obtained by experimental measurement. *Nat. Commun.* 2023, 14 (1): 1672.
- 119 Yang, D., Li, L., Li, X., Xi, W., Zhang, Y., Liu, Y., Wei, X., Zhou, W., Wei, F., Xie, S., Liu, H. Preparing high-concentration individualized carbon nanotubes for industrial separation of multiple single-chirality species. *Nat. Commun.* 2023, 14 (1): 2491.
- 120 Lin, Y., Cao, Y., Ding, S., Zhang, P., Xu, L., Liu, C., Hu, Q., Jin, C., Peng, L.-M., Zhang, Z. Scaling aligned carbon nanotube transistors to a sub-10 nm node. *Nat. Electron.* 2023, 6 (7): 506–515.
- 121 Auth, C., Aliyarukunju, A., Asoro, M., Bergstrom, D., Bhagwat, V., Birdsall, J., Bisnik, N., Buehler, M., Chikarmane, V., Ding, G., Fu, Q., Gomez, H., Han, W., Hanken, D., Haran, M., Hattendorf, M., Heussner, R., Hiramatsu, H., Ho, B., Jaloviar, S., Jin, I., Joshi, S., Kirby, S., Kosaraju, S., Kothari, H., Leatherman, G., Lee, K., Leib, J., Madhavan, A., Maria, K., Meyer, H., Mule, T., Parker, C., Parthasarathy, S., Peltó, C., Pipes, L., Post, I., Prince, M., Rahman, A., Rajamani, S., Saha, A., Santos, J.D., Sharma, M., Sharma, V., Shin, J., Sinha, R., Smith, R., Sprinkle, M., St Amour, A., Staus, C., Suri, R., Towner, D., Tripathi, A., Tura, A., Ward, C., Yeoh, A. A 10nm high performance and low-power CMOS technology featuring 3rd generation FinFET transistors, self-aligned quad patterning, contact over active gate and cobalt local interconnects. In: *2017 IEEE International Electron Devices Meeting (IEDM)*, IEEE, 2017.



- 122 Wu, W., Ma, H., Cai, X., Han, B., Li, Y., Xu, K., Lin, H., Zhang, F., Chen, Z., Zhang, Z., Peng, L.-M., Wang, S. High-speed carbon nanotube photodetectors for 2  $\mu\text{m}$  communications. *ACS Nano* 2023, 17 (15): 15155–15164.
- 123 Charlier, J.-C., Blase, X., Roche, S. Electronic and transport properties of nanotubes. *Rev. Mod. Phys.* 2007, 79 (2): 677–732.
- 124 Yang, L., Wang, S., Zeng, Q., Zhang, Z., Peng, L. Carbon nanotube photoelectronic and photovoltaic devices and their applications in infrared detection. *Small* 2013, 9 (8): 1225–1236.
- 125 Avouris, P., Freitag, M., Perebeinos, V. Carbon-nanotube photonics and optoelectronics. *Nat. Photonics* 2008, 2 (6): 341–350.
- 126 Fang, Y., Liu, Y., Qi, L., Xue, Y., Li, Y. 2D graphdiyne: an emerging carbon material. *Chem. Soc. Rev.* 2022, 51 (7): 2681–2709.
- 127 Sang, P., Ma, X., Wang, Q., Wei, W., Wang, F., Wu, J., Zhan, X., Li, Y., Chen, J. Toward high-performance monolayer graphdiyne transistor: strain engineering matters. *Appl. Surf. Sci.* 2021, 536: 147836.
- 128 Zhang, Y., Huang, P., Guo, J., Shi, R., Huang, W., Shi, Z., Wu, L., Zhang, F., Gao, L., Li, C., Zhang, X., Xu, J., Zhang, H. Graphdiyne-based flexible photodetectors with high responsivity and detectivity. *Adv. Mater.* 2020, 32 (23): 2001082.
- 129 He, J., Wang, N., Cui, Z., Du, H., Fu, L., Huang, C., Yang, Z., Shen, X., Yi, Y., Tu, Z., Li, Y. Hydrogen substituted graphdiyne as carbon-rich flexible electrode for lithium and sodium ion batteries. *Nat. Commun.* 2017, 8 (1): 1172.

