Dan Liu, Xuan Xie

Graphene: The magic bullet in functional coatings – also against corrosion?

Inspired by the amazing properties of graphene and its chemical “relatives” graphene oxide, reduced graphene oxide, few layer graphene (see Fig. 1), their use for many applications has been proposed and actually tested. A first overview was provided rather early – following the initial enthusiasm [1].

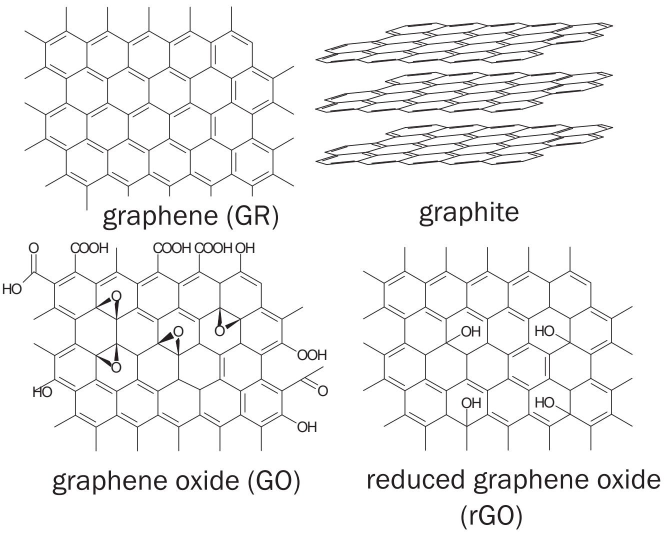

Fig. 1: **Chemical structures of graphite, GR, GO, and rGO.**

Functional coatings were among the particularly promising candidate applications. Examples in electrochemical energy technology have been reviewed recently [2-4]. Corrosion protection is a highly relevant and challenging application of functional coatings. Most coatings currently applied have some drawbacks: They are electronically insulating, they have limited stability, and they offer only limited protection. Some highly efficient coatings containing e.g. heavy metals have been discontinued for environmental reasons. Thus the materials of Fig. 1 appeared to offer a welcome relief. Early reports on corrosion protection of e.g. copper by a conformal graphene coating suggested promising perspectives [5]. But quickly it turned out that only a perfect coating provided the advantages: Impermeable for all corrosive agents and electronically conducting. Once there is a defect where corrosive agents can reach the metal surface to be protected, severe corrosion may proceed. This can be understood along the line of reasoning known for a long time from corrosion protection with metals or other coatings more noble (higher in the electrochemical series) than the coated metal: Dioxygen reduction will proceed on the large area of the coating, anodic metal dissolution will proceed at the defect as illustrated in Fig. 2: The case of pitting corrosion. Already imperfect coating as noticed in Ref. [5] may have this unwelcome effect. Experimental evidence obtained with measurements of “corrosion elements” place graphene among the noble metals [6].

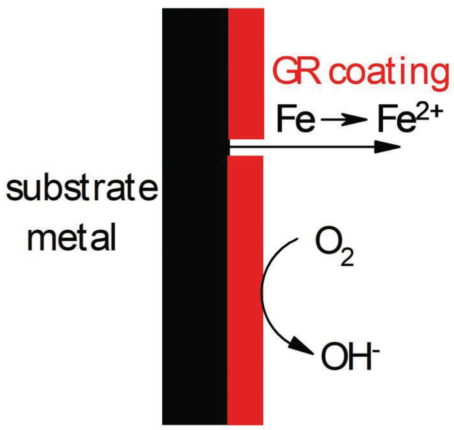

Fig. 2: **Corrosion at a defect in a graphene coating.**

To achieve such perfect coatings under industrial conditions may turn out to be an insurmountable challenge. More realistic modes of coating like

- chemical vapor deposition from gaseous precursors seems to be currently the only option to obtain more or less perfect, defect-free coatings.
- deposition or adsorption from dispersions of the coating material
- hydrothermal reduction of GO to rGO (not GR) deposited from rGO dispersion
- electrophoretic deposition
- inkjet printing

are still under investigation, in particular for applications where other advantages like electronic conductivity and permeability for metal ions come into play when applying e.g. a graphene coating on a lithium metal electrode to be used in a lithium (not lithium ion) accumulator. Such coating suppresses the corrosion of the electrode, but even more important it facilitates smooth metal deposition by enabling lithium-ion passage avoiding the dreaded dendrite formation.

Dr. Dan Liu[1] and Dr. Xuan Xie[2]
[1] Institute of Corrosion Science and Technology, Guangzhou, Guangdong Province, China, dliu@icost.ac.cn
[2] Key Laboratory for Anisotropy and Texture of Materials (MoE), School of Materials Science and Engineering, Northeastern University, Shenyang 110819, China
Correspondence: dliu@icost.ac.cn, xxie14s@alum.imr.ac.cn

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Obviously, the initial hope for the almost ideal corrosion protection coating has not materialized so far. Nevertheless, there are applications were corrosion protection, although perhaps imperfect, is only one function on e.g. negative lithium or aluminium electrode in a secondary battery. An even brighter future is the application of graphene and its relatives in composites at low contents, in the range of less than 1 %wt, yielding major improvements in inhibition efficiency [7].

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References

[1] A.K. Geim, K.S. Novoselov, *Nat. Mater.* 2007 **6**, 183-191

[2] Q. Qu, L. Fu, L. Liu, V. Kondratiev, R. Holze, *Molecules* 2025 **30**, 1436

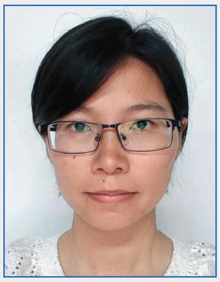
[3] X. Chen, Y. Wu, R. Holze, Corrosion and degradation in supercapacitors and mitigation approaches in: Corrosion & Degradation in Electrochemical Energy Storage and Conversion Devices (V.S. Saji Ed.), Springer, Cham 2024, 161-178

[4] D. Liu, X. Xie, X.Chen, R. Holze, *Corros. Mater. Degrad.* 2025 **6**, 33

[5] X. Xu, D. Yi, Z. Wang, J. Yu, Z. Zhang, R. Qiao, Z. Sun, Z. Hu, P. Gao, H. Peng, Z. Liu, D. Yu, E. Wang, Y. Jiang, F. Ding, K. Liu, *Adv. Mater.* 2018 **30**, 1702944

[6] P.R. Roberge, Handbook of Corrosion Engineering, 3. Ausg., McGraw-Hill, New York, USA 2019, S. 132.

[7] D. Liu, X. Xie, X.Chen, R. Holze, submitted to *J. Compos. Sci*



Dr. Dan Liu

Dan Liu is a specially-appointed associate researcher at Institute of Corrosion Science and Technological in Guangzhou, China. She received her bachelor degree from Central South University in 2014 and her PhD degree from University of Science and Technology of China in 2019. In 2025, she completed postdoctoral research at the Institute of Metal Research, Chinese Academy of Sciences. Her current main research interest is the development of surface treatment technologies and corrosion protection processes for materials. The annual sales volume of the surface treatment plating solution she developed has reached several million RMB.

Dr. Xuan Xie

Xuan Xie is a PVD process engineer at Intel Semiconductor Dalian, China. She received her bachelor and PhD degrees in 2014 and 2019, respectively, from Northeastern University, China. From 2014 to 2019, she completed her studies on photoelectrochemical cathodic protection of metals at Northeastern University and Institute of Metal Research, Chinese Academy of Sciences, in Shenyang. She further pursues research interests in corrosion and corrosion protection.

Spotlight on

Electrochemical separations

Electrochemical methods in analytical chemistry profit in quantitative terms very much from Faraday's law providing high sensitivity when combined with much advanced electronics enabling measurement of extremely small currents and tiny electrical charges directly related to amounts of matter and concentrations. One problem remains: Selectivity. This can be addressed, for example, by using sophisticated voltammetric techniques like differential pulse voltammetry. Alternatively, electrochemical separation techniques like electrophoresis and its methodological variations can substantially enhance selectivity. This is at the center of attention of the Matysik research group at the Institute of Analytical Chemistry at Regensburg University. Capillary electrophoresis coupled with amperometric detection shows more powerful handling of complex sample mixtures than differential pulse voltammetry (DPV) whereas the latter method is faster [1]. Even more analytical information can be gained through hyphenated systems that integrate mass spectrometry. The Matysik group has pioneered several such combined electrochemical approaches, including electrochemistry – capillary electrophoresis – mass spectrometry [2], and capillary electrophoresis with dual detection (amperometry/mass spectrometry) [3].

[https://go.ur.de/matysik]

References

[1] S. Ivakh, M. Koall, J. Barek, F.-M. Matysik, *Talanta* 2025 **288**, 122729

[2] T. Herl, F.-M. Matysik, *ChemElectroChem* 2020 **7**, 2498

[3] D. Böhm, M. Koall, F.-M. Matysik, *Electrophoresis* 2023 **44**, 429

Rudolf Holze