Scientific Presentation

Marco Favaro
Helmholtz-Zentrum Berlin für Materialien und Energie GmbH
Institute for Solar Fuels (EE-IF)

Email: marco.favaro@helmholtz-berlin.de

Statement of Research

During the PhD, my research was focused on the detailed surface science study of model catalysts for energetics applications (such as the oxygen reduction reaction, ORR) and water remediation. The studied model systems were carbon-based substrates that were modified by means of ion implantation. On these substrates, active phases such as Pt, Pd, Cu, Ag, Co, Fe, Fe and Co oxides, Au, Ag-Cu, Pd-Cu, Pd-Y and Pd-Ce alloys were deposited (via PVD) and studied in-situ by surface science and synchrotron radiation techniques such as XPS, FT-IRAS, HR-PES, ResPES, XAS, UPS and STM. The catalytic activity of these model catalysts was studied ex-situ using the common tools provided by electrochemistry, such as CV, RDE and EIS.

The research interests have then moved towards the preparation of single layer graphene (SLG) on metal substrates, by CVD and UHV-assisted CVD deposition. The obtained systems, also doped with B, N or S, were investigated because of their peculiar interaction with metal/metal oxides/metal chalcogenides (such as Ni, Fe, Ti, Co, Mo and their oxides, Pt, $MoS_{x,x=2,3}$), as proved by XPS, HR-PES, ResPES, XAS, UPS and *micro*-ARPES, as well as STM. Not only surface science: during the PhD my research was also focused on the preparation of 3D hierarchical and nano-shaped graphene-derived materials (such as Graphene Papers, Graphene Foams and Graphene Quantum Dots), obtained by different approaches (electrochemical ablation or hydrothermal synthesis); the introduction of several dopants (B, N, S, and their combinations) leads to interesting optical and catalytic properties of these new materials.

As post-doc and currently as research associate, my main interest is to couple XPS and XAS with electrochemistry in a new technique, performing Ambient Pressure XPS/XAS under electrochemical conditions using both soft and tender X-rays (2.0-9.0 keV). The most important physical and chemical processes in energy material research and electrochemistry take place at interfaces between the liquid and solid phase under ambient pressure or even higher. With the previous success of soft X-ray Ambient Pressure XPS-XAS in probing the gas-solid interface, researchers have started to gain insights into the liquid-solid boundaries. This will shed new light on the understanding of the chemical changes at the electrode surfaces during realistic working conditions. Not only: these developing techniques allow to investigate *in operando* the electrical double layer (EDL) at the WE/electrolyte junction, making possible to point out the particular role played by the ionic species present in the electrolyte in the charge transfer mechanism at the electrified interphase.

In my research, synchrotron radiation techniques are widely employed in order to provide a deep insight in the chemistry/structure/properties relationships, using in particular resonant spectroscopies and angle-resolved photoelectron spectroscopies. Several beam-times were performed at the Elettra synchrotron radiation facility (TS, Italy), Diamond (OX, UK), SSRL (Menlo Park, USA), ALS (Berkeley, USA) and MaxIV (Lund, Sweden) both as user and principal investigator. Beamlines: Bach, Bear, Escamicroscopy, Material Science, Nanospectroscopy, Spectromicroscopy, (Elettra), B18 (Diamond), 7-3 and 11-2 (SSRL), 9.3.1, 9.3.2, 10.3.2, 6.3.2, 11.0.2 (ALS), HIPPIE (MaxIV).

List of Publications on Peer-Reviewed Journals

42. C. Rüdiger*, C. Valero-Vidal, **M. Favaro**, S. Agnoli, G. Granozzi, J. Kunze-Liebhäuser*, *The effect of air-aging on the electrochemical characteristics of TiO_xC_y films for electrocatalysis applications*, Chem. Electro. Chem. 2017, DOI:10.1002/celc.201700912 [DOI];
41. **M. Favaro***, F. F. Abdi, M. Lamers, E. J. Crumlin, Z. Liu, R. van de Krol, D. E. Starr*, *Light-Induced Surface Reactions at the Bismuth Vanadate/Potassium Phosphate Interface*, J. Phys. Chem. B 2017, DOI:10.1021/acs.jpcb.7b06942 [DOI];
40. **M. Favaro***, J. Yang, S. Nappini, E. Magnano, F. M. Toma, E. J. Crumlin, J, Yano, I. D. Sharp*, *Understanding the oxygen evolution reaction mechanism on CoO_x using operando ambient pressure X-ray photoelectron spectroscopy*, J. Am. Chem. Soc. 2017, 139, 8960-8970 [DOI];
39. **M. Favaro**#, H. Xiao#, T. Cheng, J. Yano*, W. A. Goddard*, E. J. Crumlin*, *Water and carbon dioxide interaction on copper surfaces, from experiment to theory* (#: these two authors have equally contributed to the work), Proc. Natl. Acc. Sci. 2017, 114, 6706-6711 [DOI];
38. D. E. Starr*, **M. Favaro**, F. F. Abdi, H. Bluhm, E. J. Crumlin, R. van de Krol, *Combining soft and hard X-ray photoelectron spectroscopy at ambient conditions for a molecular-level understanding of water splitting semiconductor/electrolyte interfaces*, J. Elect. Spectrosc. Relat. Phenom. 2017, DOI: 10.1016/j.elspec.2017.05.003 [DOI];
37. **M. Favaro**, C. Valero-Vidal, J. Eichhorn, F. M. Toma, P. N. Ross, J. Yano, Z. Liu, E. J. Crumlin*, *Elucidating the alkaline oxygen evolution reaction mechanism on Platinum*, J. Mater. Chem. A 2017, 5, 11634-11643 [DOI];
36. C. Rüdiger*, **M. Favaro**, C. Valero-Vidal, L. Calvillo, N. Bozzolo, S. Jacomet, J. Hein, L. Gregoratti, S. Agnoli, G. Granozzi, J. Kunze-Liebhäuser*, *Substrate grain-dependent chemistry of carburized planar anodic TiO_2 on polycrystalline Ti*, ACS Omega, 2017, 2, 631-640 [DOI];
35. **M. Favaro**#, W. S. Drisdell#, J. M. Gregoire, E. J. Crumlin*, J. Haber*, J. Yano*, *An operando investigation of $(Ni\text{-}Fe\text{-}Co\text{-}Ce)O_x$ system as highly efficient electrocatalyst for oxygen evolution reaction*, ACS Catalysis, 2017, 7, 1248-1258 (#: these two authors have equally contributed to the work) [DOI];
34. A. Eilert, F. Cavalca, F. S. Roberts, J. Osterwalder, C. Liu, **M. Favaro**, E. J. Crumlin, H. Ogasawara, D. Friebel, L. G. M. Pettersson, A. Nilsson*, *Subsurface oxygen in oxide-derived copper electrocatalysts for carbon dioxide reduction*, J. Phys. Chem. Lett., 2017, 8, 285-290 [DOI];
33. C. Ampelli*, F. Tavella, C. Genovese, S. Perathoner, **M. Favaro**, G. Centi, *Analysis of the factors controlling performances of Au-doped TiO_2 nanotube array based photoanode in photo-electrocatalytic (PECa) cells*, J. Energy Chem. 2017, doi:10.1016/j.jechem.2016.11.004 [DOI];
32. J. Yang, J. K. Cooper, F. M. Toma, K. A. Walczak, **M. Favaro**, J. W. Beeman, L. H. Hess, C. Wang, C. Zhu, S. Gul, J. Yano, C. Kisielowski, A. Schwartzberg, I. D. Sharp*, *A multifunctional biphasic water splitting catalyst tailored for integration with high performance semiconductor photoanodes*, Nat. Mater. 2017, 16, 335-341 [DOI];
31. **M. Favaro**, B. Jeong, P. N. Ross, J. Yano, Z. Hussain, Z. Liu*, E. J. Crumlin*, *Unravelling the electrochemical double layer by direct probing of the solid/liquid interface*, Nat. Commun. 2016, 7, 12695 [DOI];
30. H.-J. Lewerenz*, M. F. Lichterman*, M. H. Richter, E. J. Crumlin, S. Hu, S. Axnanda, **M. Favaro**, W. S. Drisdell, Z. Hussain, B. S. Brunschwig, Z. Liu, A. Nilsson, A. T. Bell, N. S. Lewis*, D. Friebel, *Operando analyses of solar fuels light absorbers and catalysts*, Electrochim. Acta 2016, 211, 711-719 [DOI];
29. C. Rüdiger*, **M. Favaro**, C. Valero-Vidal, L. Calvillo, N. Bozzolo, S. Jacomet, J. Hein, L. Gregoratti, M. Amati, S. Agnoli, G. Granozzi, J. Kunze-Liebhäuser*, *Ti substrate grain dependent C/TiO_2 composites through carbothermal treatment of anodic TiO_2*, Phys. Chem. Chem. Phys. 2016, 18, 9220-9231 [DOI];

28. S. Agnoli*, **M. Favaro**, *Doping graphene with boron: a review of synthesis methods, physicochemical characterization, and emerging applications*, J. Mater. Chem. A 2016, 4, 5002-5025 (The paper has been marked as HOT by Journal of Materials Chemistry A in 2016 as recommended by referees. Within the top 30 most cited articles published in Journal of Materials Chemistry A in 2016) [DOI];

27. G. D. Nguyen, F. M. Toma, T. Cao, Z. Pedramrazi, C. Chen, D. J. Rizzo, T. Joshi, C. Bronner, Y.-C. Chen, **M. Favaro**, S. G. Louie, F. R. Fischer, M. F. Crommie*, *Bottom-up synthesis of N=13 sulfur-doped graphene nanoribbons*, J. Phys. Chem. C 2016, 120, 2684-2687 [DOI];

26. M. Bersani, A. Paduano, **M. Favaro**, P. Koshy, C. C. Sorrell, A. Martucci*, G. Granozzi, *Preparation of high-porosity TiOxCy powders from a single templating carbon source*, Ceramics International 2016, 42, 7690-7696 [DOI];

25. M. F. Lichterman, M. H. Richter, S. Hu, E. J. Crumlin, S. Axnanda, **M. Favaro**, W. Drisdell, Z. Hussain, B. S. Brunschwig, N. S. Lewis*, Z. Liu, H.-J. Lewerenz, *An Electrochemical, microtopographical and ambient pressure-X-ray photoelectron spectroscopic investigation of Si/TiO_2/Ni/electrolyte interfaces*, J. Electrochem. Soc. 2016, 163, H139-H146 [DOI];

24. **M. Favaro**, G. Rizzi, S. Nappini, E. Magnano, F. Bondino, S. Agnoli, G. Granozzi*, *A synchrotron-based spectroscopic study of the electronic structure of N-doped HOPG and PdY/N-doped HOPG*, Surf. Sci. 2016, 646, 132-139 (invited paper on a special issue in honor of R. Lambert) [DOI];

23. F. Carraro, L. Calvillo, M. Cattelan, **M. Favaro**, M. Righetto, S. Nappini, I. Píš, V. Celorrio, D. J. Fermín, A. Martucci, S. Agnoli*, G. Granozzi, *Fast one-pot synthesis of MoS_2/crumpled graphene p-n nanonjunctions for enhanced photoelectrochemical hydrogen production*, ACS Appl. Mat. Interfaces 2015, 7, 25685-25692 [DOI];

22. M. H. Richter, M. F. Lichterman, S. Hu, E. J. Crumlin, S. Axnanda, **M. Favaro**, W. Drisdell, Z. Hussain, T. Mayer, B. S. Brunschwig, N. S. Lewis*, Z. Liu, H.-J. Lewerenz, *Measurement of the energy-band relations of stabilized Si photoanodes using operando ambient pressure X-ray photoelectron spectroscopy*, ECS Trans. 2015, 66, 105-113 (invited paper) [DOI];

21. M. F. Lichterman, S. Hu, M. H. Richter, E. J. Crumlin, S. Axnanda, **M. Favaro**, W. Drisdell, Z. Hussain, T. Mayer, B. S. Brunschwig, N. S. Lewis*, Z. Liu, H.-J. Lewerenz, *Investigation of the Si/TiO_2/electrolyte interface using operando tender X-ray photoelectron spectroscopy*, ECS Trans. 2015, 66, 97-103 (invited paper) [DOI];

20. M. F. Lichterman, S. Hu, M. H. Richter, E. J. Crumlin, S. Axnanda, **M. Favaro**, W. Drisdell, Z. Hussain, T. Mayer, B. S. Brunschwig, N. S. Lewis*, Z. Liu, H.-J. Lewerenz, *Direct observation of the energetics at the semiconductor-liquid junction by operando X-ray photoelectron spectroscopy*, Energy Environ. Sci. 2015, 8, 2409-2416 [DOI];

19. **M. Favaro**, M. Cattelan, F. Carraro, L. Colazzo, C. Durante, M. Sambi, A. Gennaro, S. Agnoli*, G. Granozzi, *Multiple doping of graphene oxide foams and quantum dots: new switchable systems for oxygen reduction and water remediation*, J. Mater. Chem. A 2015, 3, 14334-14347 [DOI];

18. **M. Favaro**, S. Leonardi, C. Valero-Vidal, S. Nappini, M. Hanzlik, S. Agnoli*, J. Kunze-Liebhauser*, G. Granozzi, *In-situ doping of TiO_2 nanotubes via anodization in graphene oxide quantum dot containing electrolyte and carburization to TiO_xC_y nanotubes*, Adv. Mater. Interfaces 2015, 2, 1400462. Back Cover. [DOI];

17. **M. Favaro**, L. Ferrighi, G. Fazio, L. Colazzo, C. Di Valentin*, C. Durante, F. Sedona, A. Gennaro, S. Agnoli*, G. Granozzi, *Single and multi-doping in graphene quantum dots: unraveling the origin of selectivity in the oxygen reduction reaction*, ACS Catalysis 2015, 5, 129-144 (highly cited paper in 2016: "Top 1% of the academic field in Chemistry". Source: Essential Science Indicators, Web of Science, Thomson Reuters) [DOI];

16. C. Ampelli*, C. Genovese, F. Tavella, **M. Favaro**, S. Agnoli, G. Granozzi, S. Perathoner, G. Centi, *Assembling of TiO_2 nanotube photoelectrodes with enhanced visible properties for a sustainable production of H_2*, Chem. Eng. Trans. 2015, 43, 667-672 [DOI];

15. M. Cattelan, G. W. Peng, E. Cavaliere, L. Artiglia, A. Barinov, L. T. Roling, **M. Favaro**, I. Pis, S. Nappini,

E. Magnano, F. Bondino, L. Gavioli, S. Agnoli*, M. Mavrikakis, G. Granozzi, *The nature of the Fe-graphene interface at the nanometric level*, Nanoscale 2015, 7, 2450-2460 [DOI];

14. L. Perini, C. Durante*, **M. Favaro**, O. Schneider, G. Granozzi, A. Gennaro, *Effect of nitrogen doping on platinum and palladium nanoparticles supported on mesoporous carbon for oxygen reduction reaction*, ACS Appl. Mat. Interfaces 2015, 7, 1170-1179 [DOI];

13. W. Ju, T. Brülle, **M. Favaro**, L. Perini, C. Durante, O. Schneider*, U. Stimming, *Palladium nanoparticles supported on highly oriented pyrolytic graphite: preparation, reactivity and stability*, Chem. Electro. Chem. 2015, 2, 547-558 [DOI];

12. F. Lamberti, L. Brigo, **M. Favaro**, C. Luni, A. Zoso, M. Cattelan, S. Agnoli, G. Granozzi, G. Brusatin, M. Giomo, N. Elvassore*, *Opto-electrochemical biorecognition by optically-transparent highly conductive graphene-modified fluorine-doped tin oxide substrates*, ACS Appl. Mat. Interfaces 2014, 6, 22769-22777 [DOI];

11. L. Calvillo, D. Fittipaldi, C. Rüdiger, S. Agnoli, **M. Favaro**, C. Valero-Vidal, C. Di Valentin, A. Vittadini, N. Bozzolo, S. Jacomet, L. Gregoratti, J. Kunze-Liebhäuser, G. Pacchioni, G. Granozzi*, *The carbothermal transformation of TiO_2 into TiO_xC_y in UHV: tracking intrinsic chemical stabilities*, J. Phys. Chem. C 2014, 118, 22601-22610 [DOI];

10. D. Mazzier, **M. Favaro**, S. Agnoli, S. Silvestrini, G. Granozzi, M. Maggini, A. Moretto*, *Synthesis of luminescent 3D microstructures formed by carbon quantum dots and their self-assembly properties*, Chem. Commun. 2014, 50, 6592-6595 [DOI];

9. **M. Favaro**, S. Agnoli*, M. Cattelan, A. Moretto, C. Durante, S. Leonardi, J. Kunze-Liebhäuser, O. Schneider, A. Gennaro, G. Granozzi, *Shaping graphene oxide by electrochemistry: from foams to self-assembled molecular materials*, Carbon 2014, 77, 405-415 [DOI];

8. C. Durante, V. Perazzolo, A. A. Isse, **M. Favaro**, G. Granozzi, A. Gennaro*, *Electrochemical activation of carbon-halogen bonds: electrocatalysis at palladium/copper nanoparticles*, Chem. Electro. Chem. 2014, 1, 1370-1381 [DOI];

7. W. Ju#, **M. Favaro**#, C. Durante, S. Agnoli, O. Schneider*, U. Stimming, Gaetano Granozzi, *Pd Nanoparticles deposited on nitrogen-doped HOPG: New insights into the Pd-catalyzed oxygen reduction reaction*, Electrochimica Acta 2014, 141, 89-101 (#: these two authors have equally contributed to the work) [DOI];

6. C. Durante, V. Perazzolo, L. Perini, **M. Favaro**, G. Granozzi, A. Gennaro*, *Electrochemical activation of carbon-halogen bonds: electrocatalysis at silver/copper nanoparticles*, Appl. Cat. B: Environ. 2014, 158-159, 286-295 [DOI];

5. L. Perini, C. Durante, **M. Favaro**, S. Agnoli, G. Granozzi, A. Gennaro*, *Electrocatalysis at palladium nanoparticles: Effect of the support nitrogen doping on the catalytic activation of carbon halogen bond*, Appl. Cat. B: Environ. 2014, 144, 300-307 [DOI];

4. **M. Favaro**, S. Agnoli*, C. Di Valentin, C. Mattevi, M. Cattelan, L. Artiglia, E. Magnano, F. Bondino, S. Nappini, G. Granozzi, *TiO_2/Graphene nanocomposites from the direct reduction of graphene oxide by metal evaporation*, Carbon 2014, 68, 319-329 [DOI];

3. M.Cattelan, S. Agnoli, **M. Favaro**, D. Garoli, F. Romanato, M. Meneghetti, A. Barinov, P. Dudin, G. Granozzi, *Microscopic view on a chemical vapor deposition route to boron-doped graphene nanostructure*, Chem. Mater. 2013, 25, 1490-1495 [DOI];

2. **M. Favaro**, S. Agnoli, L. Perini, C. Durante, A. Gennaro, G. Granozzi*, *Palladium nanoparticles supported on nitrogen-doped HOPG: a surface science and electrochemical study*, Phys. Chem. Chem. Phys. 2013, 15, 2923-2931 [DOI];

1. **M. Favaro**, L. Perini, S. Agnoli, C. Durante, G. Granozzi, A. Gennaro*, *Electrochemical behavior of N and Ar implanted highly oriented pyrolytic graphite substrates and activity toward oxygen reduction reaction*, Electrochimica

Acta 2013, 88, 477-487 [DOI].

Scientific Reports

1. **M. Favaro**, Z. Liu, E. J. Crumlin, *Ambient-Pressure X-ray Photoelectron Spectroscopy to Characterize the Solid/Liquid Interface: Probing the Electrochemical Double Layer*, Synchrotron Radiation News 2017, 30, 38-40 [DOI].