While the use of these ECL materials has resulted in increased ECL emission, they have concurrently increased the complexity of the mechanisms being employed. This is apparent in systems employing multiple strategies simultaneously in the form of composites or functionalized scaffolds, NP, and QDs [21,22,25,118-122].

13.8 Conclusions and perspectives

ECL provides a unique platform for developing assays stemming from the orthogonal nature of generating the excited state and collecting light emission. This electrochemical trigger not only provides the researcher spatial control and temporal control during the experiment, but makes a rich selection of heterogeneous and homogeneous chemistries available when determining how to achieve ECL. Not only is this exciting in terms of improving ECL performance, but also because ECL provides a rare opportunity to probe Marcus' ET theory.

In addition to academic pursuits, the trajectory of ECLs future can be scried from its permeation of the industrial sector, where multiple ECL-based assays have been commercialized for both biological and analytical applications. This makes further exploration of ECL significant to both advancing our understanding of coupled heterogeneous and homogenous reactions and ECLs application as an assay.

References

[1] L.D. Johnson, Chemiluminescence or cold light investigations, J. Chem. Educ. 17 (6) (1940) 295, doi:10.1021/ed017p295.

[2] U. Isacsson, G. Wettermark, Chemiluminescence in analytical chemistry, Anal. Chim. Acta 68 (2) (1974) 339–362, doi:10.1016/S0003-2670(01)82590-3.

[3] J.D. Ingle, S.R. Crouch, Spectrochemical Analysis; Prentice Hall: upper Saddle River, 1988.

[4] F. McCapra, D.G. Richardson, The mechanism of chemiluminescence: a new chemiluminescent reaction, Tetrahedron Lett. 5 (43) (1964) 3167–3172, doi:10.1016/0040-4039(64)83128-2.

[5] R.E. Kellogg, Mechanism of chemiluminescence from peroxy radicals, J. Am. Chem. Soc. 91 (20) (1969) 5433–5436, doi:10.1021/ja01048a005.

[6] J. Arnhold, S. Mueller, K. Arnold, K. Sonntag, Mechanisms of inhibition of chemiluminescence in the oxidation of luminol by sodium hypochlorite, J. Biolumin. Chemilumin. 8 (6) (1993) 307–313, doi:10.1002/bio.1170080604.

[7] A.L. Rose, T.D. Waite, Chemiluminescence of luminol in the presence of iron(II) and oxygen: oxidation mechanism and implications for its analytical use, Anal. Chem. 73 (24) (2001) 5909–5920, doi:10.1021/ac015547q.

[8] A.J. Bard, Electrogenerated chemiluminescence, in: A Bard (Ed.), Electrogenerated Chemiluminescence, Marcel Dekker, Inc, 2004.

[9] W. Miao, Electrogenerated chemiluminescence and its biorelated applications, Chem. Rev 108 (7) (2008) 2506–2553, doi:10.1021/cr068083a.

[10] L.R. Faulkner, A.J. Bard, Electrogenerated chemiluminescence. I. mechanism of anthracene chemiluminescence in N,N-Dimethylformamide solution., J. Am. Chem. Soc. 90 (23) (1968) 6284–6290, doi:10.1021/ja01025a006.

[11] R. Pyati, M.M. Richter, ECL-electrochemical luminescence. annu. rep. prog., Chem. Sect. C Phys. Chem. 103 (0) (2007) 12–78, doi:10.1039/B605635K.
[12] S. Shrivastava, T.Q. Trung, N.E Lee, recent progress{,} challenges{,} and prospects of fully integrated mobile and wearable point-of-care testing systems for self-testing, Chem. Soc. Rev. 49 (6) (2020) 1812–1866, doi:10.1039/C9CS00319C.
[13] T. Broger, M. Tsionksy, A. Mathew, T.L. Lowary, A. Pinter, T. Plisova, D. Bartlett, S. Barbero, C.M. Denkinger, E. Moreau, K. Katsuragi, M. Kawasaki, P. Nahid, G.B. Sigal, Sensitive electrochemiluminescence (ECL) immunoassays for detecting lipoarabinomannan (LAM) and ESAT-6 in urine and serum from tuberculosis patients, PLoS One 14 (4) (2019) e0215443.
[14] Y. Zhang, R. Zhang, X. Yang, H. Qi, C. Zhang, Recent advances in electrogenerated chemiluminescence biosensing methods for pharmaceuticals, J. Pharm. Anal. 9 (1) (2019) 9–19, doi:10.1016/j.jpha.2018.11.004.
[15] D.M. Hercules, Chemiluminescence resulting from electrochemically generated species, Science 145 (3634) (1964) 808–809, doi:10.1126/science.145.3634.808.
[16] L.R. Faulkner, B. T.-M. in E. [40]Chemiluminescence from electron-transfer processes, Bioluminescence and Chemiluminescence, 57, Academic Press, 1978, pp. 494–526, doi:10.1016/0076-6879(78)57042-0.
[17] K.S.V. Santhanam, A.J. Bard, Chemiluminescence of electrogenerated 9,10-diphenylanthracene anion radical1, J. Am. Chem. Soc. 87 (1) (1965) 139–140, doi:10.1021/ja01079a039.
[18] W.L. Wallace, A.J. Bard, Electrogenerated chemiluminescence. 35. temperature dependence of the ECL efficiency of tris(2,2'-Bipyridine)rubidium(2+) in acetonitrile and evidence for very high excited state yields from electron transfer reactions, J. Phys. Chem. 83 (10) (1979) 1350–1357, doi:10.1021/j100473a022.
[19] L. Hu, G. Xu, Applications and Trends in Electrochemiluminescence, Chem. Soc. Rev. 39 (8) (2010) 3275–3304, doi:10.1039/B923679C.
[20] A.W. Knight, A review of recent trends in analytical applications of electrogenerated chemiluminescence, TrAC, Trends Anal. Chem. 18 (1) (1999) 47–62, doi:10.1016/S0165-9936(98)00086-7.
[21] D. Wang, Y. Liang, Y. Su, Q. Shang, C. Zhang, Sensitivity enhancement of cloth-based closed bipolar electrochemiluminescence glucose sensor via electrode decoration with chitosan/multi-walled carbon nanotubes/graphene quantum dots-gold nanoparticles, Biosens. Bioelectron. 130 (2019) 55–64, doi:10.1016/j.bios.2019.01.027.
[22] Y. Jian, H. Wang, X. Sun, L. Zhang, K. Cui, S. Ge, J. Yu, Electrochemiluminescence cytosensing platform based on ru(Bpy)32+@silica-Au nanocomposite as luminophore and aupd nanoparticles as coreaction accelerator for in situ evaluation of intracellular H2O2, Talanta 199 (2019) 485–490, doi:10.1016/j.talanta.2019.03.006.
[23] P. Bertoncello, P. Ugo, Recent advances in electrochemiluminescence with quantum dots and arrays of nanoelectrodes, Chem. Electro. Chem. 4 (7) (2017) 1663–1676, doi:10.1002/celc.201700201.
[24] D. Tian, C. Duan, W. Wang, H. Cui, Ultrasensitive electrochemiluminescence immunosensor based on luminol functionalized gold nanoparticle labeling, Biosens. Bioelectron. 25 (10) (2010) 2290–2295, doi:10.1016/j.bios.2010.03.014.
[25] Y. Bae, D.C. Lee, E.V. Rhogojina, D.C. Jurbergs, B.A. Korgel, A.J. Bard, Electrochemistry and electrogenerated chemiluminescence of films of silicon nanoparticles in aqueous solution, Nanotechnology 17 (15) (2006) 3791–3797, doi:10.1088/0957-4484/17/15/030.
[26] A. Bard, L. Faulkner, Electrochemical Methods, Electrochemical Methods: Fundamentals and Applications (2001).

[27] S.A. Cruser, A.J. Bard, Electrogenerated chemiluminescence. III. intensity-time and concentration-intensity relation and the lifetime of radical cations of aromatic hydrocarbons in N,N-dimethylformamide solution, J. Am. Chem. Soc. 91 (2) (1969) 267–275, doi:10.1021/ja01030a010.

[28] S.W. Feldberg, Theory of controlled potential electrogeneration of chemiluminescencel, J. Am. Chem. Soc. 88 (3) (1966) 390–393, doi:10.1021/ja00955a002.

[29] L.R. Faulkner, A new approach to the analysis of chemiluminescence transients from step experiments, J. Electrochem. Soc. 122 (9) (1975) 1190–1195, doi:10.1149/1.2134423.

[30] R. Manzoor, L. Wang, H. Wang, Y. Lei, A. Sehrish, M.S. Khan, A. Ali, D. Wu, Q. Wei, Ultrasensitive competitive electrochemiluminescence immunosensor based on luminol-AuNPs@Mo2C and upconversion nanoparticles for detection of diethylstilbestrol, Microchem. J. 158 (2020) 105283, doi:10.1016/j.microc.2020.105283.

[31] J.M. Savéant, Elements of Molecular and Biomolecular. In: Electrochemistry: an Electrochemical Approach to Electron Transfer Chemistry, John Wiley & Sons, 2006 Vol. 13.

[32] R.A. Marcus, Electron transfer reactions in chemistry. Theory and Experiment, Rev. Mod. Phys. 65 (3) (1993) 599–610, doi:10.1103/RevModPhys.65.599.

[33] W.F. Libby, Theory of electron exchange reactions in aqueous solution, J. Phys. Chem. 56 (7) (1952) 863–868, doi:10.1021/j150499a010.

[34] A.S. Coolidge, H.M. James, R.D. Present, A study of the franck-condon principle, J. Chem. Phys. 4 (3) (1936) 193–211, doi:10.1063/1.1749818.

[35] K.J. Laidler, M.C. King, Development of transition-state theory, J. Phys. Chem. 87 (15) (1983) 2657–2664, doi:10.1021/j100238a002.

[36] P.F. Barbara, T.J. Meyer, M.A. Ratner, Contemporary issues in electron transfer research, J. Phys. Chem. 100 (31) (1996) 13148–13168, doi:10.1021/jp9605663.

[37] R.Y. Lai, A.J. Bard, Electrogenerated chemiluminescence. 70. The application of ECL to determine electrode potentials of tri-n-propylamine, its radical cation, and intermediate free radical in MeCN/benzene solutions, J. Phys. Chem. A 107 (18) (2003) 3335–3340, doi:10.1021/jp026743j.

[38] L.R. Faulkner, A.J. Bard, Magnetic field effects on anthracene triplet-triplet annihilation in fluid solutions, J. Am. Chem. Soc. 91 (23) (1969) 6495–6497, doi:10.1021/ja01051a056.

[39] H. Tachikawa, A.J. Bard, Electrogenerated chemluminescence. Effect of solvent and magnetic field on ECL of rubrene systems, Chem. Phys. Lett. 26 (2) (1974) 246–251, doi:10.1016/0009-2614(74)85407-2.

[40] S.M. Park, D.A. Tryk, Excited state intermediates probed by electrogenerated chemiluminescence, Rev. Chem. Intermed. 4 (1) (1981) 43–79, doi:10.1007/BF03052412.

[41] L.R. Faulkner, A.J. Bard, Electrogenerated chemiluminescence. IV. Magnetic field effects on the electrogenerated chemiluminescence of some anthracenes, J. Am. Chem. Soc 91 (1) (1969) 209–210, doi:10.1021/ja01029a049.

[42] H. Uoyama, K. Goushi, K. Shizu, H. Nomura, C. Adachi, Highly efficient organic light-emitting diodes from delayed fluorescence, Nature 492 (2012) 234.

[43] Y.Y. Cheng, B. Fückel, T. Khoury, R.G.C.R. Clady, M.J.Y. Tayebjee, N.J. Ekins-Daukes, M.J. Crossley, T.W. Schmidt, Kinetic analysis of photochemical upconversion by triplet–triplet annihilation: beyond any spin statistical limit, J. Phys. Chem. Lett. 1 (12) (2010) 1795–1799, doi:10.1021/jz100566u.

[44] W.W. Brandt, F.P. Dwyer, E.D. Gyarfas, Chelate complexes of 1,10-phenanthroline and related compounds, Chem. Rev. 54 (6) (1954) 959–1017, doi:10.1021/cr60172a003.

[45] S.-.W. Yang, A. Elangovan, T.-.I. Ho, Donor-substituted phenyl-π-chromones: electrochemiluminescence and intriguing electronic properties, Photochem. Photobiol. Sci 4 (4) (2005) 327–332, doi:10.1039/B416319B.

[46] J. Suk, P. Natarajan, J.N. Moorthy, A.J. Bard, Electrochemistry and electrogenerated chemiluminescence of twisted anthracene-functionalized bimesitylenes, J. Am. Chem. Soc. 134 (7) (2012) 3451–3460, doi:10.1021/ja209894q.

[47] A.B. Nepomnyashchii, R.J. Ono, D.M. Lyons, C.W. Bielawski, J.L. Sessler, A.J. Bard, Electrochemistry and electrogenerated chemiluminescence of thiophene and fluorene oligomers. benzoyl peroxide as a coreactant for oligomerization of thiophene dimers, Chem. Sci. 3 (8) (2012) 2628–2638, doi:10.1039/C2SC20263H.

[48] K.M. Omer, S.-.Y. Ku, J.-.Z. Cheng, S.-.H. Chou, K.-.T. Wong, A.J. Bard, Electrochemistry and electrogenerated chemiluminescence of a spirobifluorene-based donor (Triphenylamine)–acceptor (2,1,3-Benzothiadiazole) molecule and its organic nanoparticles, J. Am. Chem. Soc. 133 (14) (2011) 5492–5499, doi:10.1021/ja2000825.

[49] N.E. Tokel, A.J. Bard, Electrogenerated chemiluminescence. IX. Electrochemistry and emission from systems containing tris(2,2'-Bipyridine)ruthenium(II) dichloride, J. Am. Chem. Soc. 94 (8) (1972) 2862–2863, doi:10.1021/ja00763a056.

[50] F.E. Lytle, D.M. Hercules, Luminescence of tris(2,2'-Bipyridine)ruthenium(II) dichloride, J. Am. Chem. Soc. 91 (2) (1969) 253–257, doi:10.1021/ja01030a006.

[51] D.M. Roundhill, Coverage includes the transition metals, lanthanide and actinide complexes, metal porphyrins, and many other complexes, in: D.M. Roundhill (Ed.), Photochemistry, photophysics, and photoredox reactions of Ru(Bpy)32+and related complexes BT - photochemistry and photophysics of metal complexes, Springer US, Boston, MA, 1994, pp. 165-215, doi:10.1007/978-1-4899-1495-8_5.

[52] J.N. Demas, G.A. Crosby, On the multiplicity of the emitting state of ruthenium(II) complexes, J. Mol. Spectrosc. 26 (1) (1968) 72–77, doi:10.1016/0022-2852(68)90144-6.

[53] A. Fiorani, G. Valenti, M. Iurlo, M. Marcaccio, F. Paolucci, Electrogenerated chemiluminescence: a molecular electrochemistry point of view, Curr. Opin. Electrochem. 8 (2018) 31–38, doi:10.1016/j.coelec.2017.12.005.

[54] S.N. Foner, Free radicals and unstable molecules, Science 143 (3605) (1964) 441–450, doi:10.1126/science.143.3605.441.

[55] I. Rubinstein, A.J. Bard, Electrogenerated chemiluminescence. 37. Aqueous ecl systems based on tris(2,2'-Bipyridine)ruthenium(2+) and oxalate or organic acids, J. Am. Chem. Soc 103 (3) (1981) 512–516, doi:10.1021/ja00393a006.

[56] H.S. White, A.J. Bard, Electrogenerated chemiluminescence. 41. Electrogenerated chemiluminescence and chemiluminescence of the ru(2,21 - Bpy)32+-S2O82- system in acetonitrile-water solutions, J. Am. Chem. Soc. 104 (25) (1982) 6891–6895, doi:10.1021/ja00389a001.

[57] J.K. Leland, M.J. Powell, Electrogenerated chemiluminescence: an oxidative-reduction type ecl reaction sequence using tripropyl amine, J. Electrochem. Soc 137 (10) (1990) 3127–3131, doi:10.1149/1.2086171.

[58] W. Miao, J.-.P. Choi, A.J. Bard, Electrogenerated chemiluminescence 69: The tris(2,2'-Bipyridine)ruthenium(II), (Ru(Bpy)32+)/Tri-n-propylamine (TPrA) system revisiteda new route involving TPrA + cation radicals, J. Am. Chem. Soc. 124 (48) (2002) 14478–14485, doi:10.1021/ja027532v.

[59] A.W. Knight, G.M Greenway, Relationship between structural attributes and observed electrogenerated chemiluminescence (ECL) activity of tertiary amines as potential analytes for the tris(2{,}2-Bipyridine)ruthenium(II) ECL reaction, A Review. Analyst 121 (11) (1996) 101R–106R, doi:10.1039/AN996210101R.

[60] E. Kerr, E.H. Doeven, D.J.D. Wilson, C.F. Hogan, P.S. Francis, Considering the chemical energy requirements of the Tri-n-propylamine Co-reactant pathways for the judicious design of new electrogenerated chemiluminescence detection systems, Analyst 141 (1) (2016) 62–69, doi:10.1039/C5AN01462J.

[61] X. Yin, B. Sha, X. He, Electrochemiluminescence from tris(2,2′-Bipyridyl) ruthenium (II) in the presence of aminocarboxylic acid co-reactants, Sci. China Ser. B Chem. 52 (9) (2009) 1394–1401, doi:10.1007/s11426-009-0136-6.

[62] X. Liu, L. Shi, W. Niu, H. Li, G. Xu, Environmentally friendly and highly sensitive ruthenium(II) tris(2,2′-Bipyridyl) electrochemiluminescent system using 2-(Dibutylamino)ethanol as co-reactant, Angew. Chemie Int. Ed. 46 (3) (2007) 421–424, doi:10.1002/anie.200603491.

[63] N. Kebede, P.S. Francis, G.J. Barbante, C.F. Hogan, Electrogenerated chemiluminescence of tris(2,2' Bipyridine)ruthenium(II) using common biological buffers as co-reactant, Ph buffer and supporting electrolyte, Analyst 140 (21) (2015) 7142–7145, doi:10.1039/c5an01216c.

[64] Irkham, T. Watanabe, A. Fiorani, G. Valenti, F. Paolucci, Y. Einaga, Co-reactant-on-demand ECL: electrogenerated chemiluminescence by the in situ production of S2O82– at boron-doped diamond electrodes, J. Am. Chem. Soc. 138 (48) (2016) 15636–15641, doi:10.1021/jacs.6b09020.

[65] S.E.K. Kirschbaum, A.J. Baeumner, A Review of electrochemiluminescence (ECL) in and for microfluidic analytical devices, Anal. Bioanal. Chem. 407 (14) (2015) 3911–3926, doi:10.1007/s00216-015-8557-x.

[66] Z. Liu, W. Qi, G. Xu, Recent advances in electrochemiluminescence, Chem. Soc. Rev. 44 (10) (2015) 3117–3142, doi:10.1039/C5CS00086F.

[67] J. Li, Q. Yan, Y. Gao, H. Ju, Electrogenerated chemiluminescence detection of amino acids based on precolumn derivatization coupled with capillary electrophoresis separation, Anal. Chem. 78 (8) (2006) 2694–2699, doi:10.1021/ac052092m.

[68] Y. Zhang, Z. Zhang, Y. Sun, Development and optimization of an analytical method for the determination of sudan dyes in hot chilli pepper by high-performance liquid chromatography with on-line electrogenerated BrO--luminol chemiluminescence detection, J. Chromatogr. A 1129 (1) (2006) 34–40, doi:10.1016/j.chroma.2006.06.028.

[69] F.-R.F. Fan, D. Cliffel, A.J. Bard, Scanning electrochemical microscopy. 37. Light emission by electrogenerated chemiluminescence at SECM tips and their application to scanning optical microscopy, Anal. Chem. 70 (14) (1998) 2941–2948, doi:10.1021/ac980107t.

[70] J.T. Maloy, K.B. Prater, A.J. Bard, Electrogenerated chemiluminescence. V. rotating-ring-disk electrode. digital simulation and experimental evaluation, J. Am. Chem. Soc. 93 (23) (1971) 5959–5968, doi:10.1021/ja00752a003.

[71] C.P. Keszthelyi, N.E. Tokel-Takvoryan, A.J. Bard, Electrogenerated chemiluminescence. determination of the absolute luminescence efficiency in electrogenerated chemiluminescence. 9,10-diphenylanthracene-thianthrene and other systems, Anal. Chem 47 (2) (1975) 249–256, doi:10.1021/ac60352a046.

[72] M. Hesari, Z. Ding, Review—electrogenerated chemiluminescence: light years ahead, J. Electrochem. Soc 163 (4) (2016) H3116–H3131.

[73] O.V. Klymenko, I. Svir, C. Amatore, A new approach for the Simulation of Electrochemiluminescence (ECL), ChemPhysChem 14 (10) (2013) 2237–2250, doi:10.1002/cphc.201300126.

[74] S.W. Feldberg, C. Auerbach, Model for current reversal chronopotentiometry with second-order kinetic complications, Anal. Chem. 36 (3) (1964) 505–509, doi:10.1021/ac60209a055.

[75] M. Shen, J. Rodríguez-López, Y.-T. Lee, C.-T. Chen, F.-R.F. Fan, A.J. Bard, Electrochemistry and electrogenerated chemiluminescence of a novel donor–acceptor FPh-SPFN red fluorophore, J. Phys. Chem. C 114 (21) (2010) 9772–9780, doi:10.1021/jp911451v.

[76] I. Svir, A. Oleinick, O.V. Klymenko, C. Amatore, Strong and unexpected effects of diffusion rates on the generation of electrochemiluminescence by amine/transition-metal(II) systems, ChemElectroChem 2 (6) (2015) 811–818, doi:10.1002/celc.201402460.
[77] A.S. Danis, W.L. Odette, S.C. Perry, S. Canesi, H.F. Sleiman, J. Mauzeroll, Cuvette-based electrogenerated chemiluminescence detection system for the assessment of polymerizable ruthenium luminophores, ChemElectroChem 4 (7) (2017) 1736–1743, doi:10.1002/celc.201600879.
[78] A.S. Danis, K.P. Potts, S.C. Perry, J. Mauzeroll, Combined spectroelectrochemical and simulated insights into the electrogenerated chemiluminescence coreactant mechanism, Anal. Chem. 90 (12) (2018) 7377–7382, doi:10.1021/acs.analchem.8b00773.
[79] A.S. Danis, J.B. Gordon, K.P. Potts, L.I. Stephens, S.C. Perry, J. Mauzeroll, Simultaneous electrochemical and emission monitoring of electrogenerated chemiluminescence through instrument hyphenation, Anal. Chem. 91 (3) (2019) 2312–2318, doi:10.1021/acs.analchem.8b04960.
[80] X. Qin, X. Xu, J. Lu, Y. Zhu, Highly efficient electrochemiluminescence of quinoline and isoquinoline in aqueous solution, Electrochem. Commun. 101 (2019) 19–22, doi:10.1016/j.elecom.2019.02.017.
[81] E. Kerr, E.H. Doeven, G.J. Barbante, T.U. Connell, P.S. Donnelly, D.J.D. Wilson, T.D. Ashton, F.M. Pfeffer, P.S. Francis, Blue electrogenerated chemiluminescence from water-soluble iridium complexes containing sulfonated phenylpyridine or tetraethylene glycol derivatized triazolylpyridine ligands, Chemistry (Easton) 21 (42) (2015) 14987–14995, doi:10.1002/chem.201502037.
[82] G. Pu, Z. Yang, Y. Wu, Z. Wang, Y. Deng, Y. Gao, Z. Zhang, X. Lu, Investigation into the oxygen-involved electrochemiluminescence of porphyrins and its regulation by peripheral substituents/central metals, Anal. Chem. 91 (3) (2019) 2319–2328, doi:10.1021/acs.analchem.8b05027.
[83] R. Ishimatsu, E. Kunisawa, K. Nakano, C. Adachi, T. Imato, Electrogenerated chemiluminescence and electronic states of several organometallic eu(III) and tb(III) complexes: effects of the ligands, ChemistrySelect 4 (9) (2019) 2815–2831, doi:10.1002/slct.201900595.
[84] P. Bertoncello, A.J. Stewart, L. Dennany, Analytical applications of nanomaterials in electrogenerated chemiluminescence, Anal. Bioanal. Chem. 406 (23) (2014) 5573–5587, doi:10.1007/s00216-014-7946-x.
[85] N. Myung, Y. Bae, A.J. Bard, Effect of surface passivation on the electrogenerated chemiluminescence of CdSe/ZnSe nanocrystals, Nano Lett. 3 (8) (2003) 1053–1055, doi:10.1021/nl034354a.
[86] N. Myung, Z. Ding, A.J. Bard, Electrogenerated chemiluminescence of CdSe nanocrystals, Nano Lett. 2 (11) (2002) 1315–1319, doi:10.1021/nl0257824.
[87] Y. Bae, N. Myung, A.J. Bard, Electrochemistry and electrogenerated chemiluminescence of CdTe nanoparticles, Nano Lett. 4 (6) (2004) 1153–1161, doi:10.1021/nl049516x.
[88] S.K. Poznyak, D.V. Talapin, E.V. Shevchenko, H. Weller, Quantum dot chemiluminescence, Nano Lett. 4 (4) (2004) 693–698, doi:10.1021/nl049713w.
[89] X. Chen, Y. Liu, Q. Ma, Recent advances in quantum dot-based electrochemiluminescence sensors, J. Mater. Chem. C 6 (5) (2018) 942–959, doi:10.1039/C7TC05474B.
[90] H. Liu, Y. Zhang, Y. Dong, X. Chu, Electrogenerated chemiluminescence aptasensor for lysozyme based on copolymer nanospheres encapsulated black phosphorus quantum dots, Talanta 199 (2019) 507–512, doi:10.1016/j.talanta.2019.02.099.
[91] X. Liu, H. Ju, Coreactant enhanced anodic electrochemiluminescence of cdte quantum dots at low potential for sensitive biosensing amplified by enzymatic cycle, Anal. Chem. 80 (14) (2008) 5377–5382, doi:10.1021/ac8003715.

[92] Y. Shan, J.-J. Xu, H.-Y. Chen, Distance-dependent quenching and enhancing of electrochemiluminescence from a cds:mn nanocrystal film by au nanoparticles for highly sensitive detection of DNA, Chem. Commun. 28 (8) (2009) 905–907, doi:10.1039/B821049G.

[93] N. Hao, X.-L. Li, H.R. Zhang, J.-J. Xu, H.-Y. Chen, A highly sensitive ratiometric electrochemiluminescent biosensor for microRNA detection based on cyclic enzyme amplification and resonance energy transfer, Chem. Commun. 50 (94) (2014) 14828–14830, doi:10.1039/C4CC06801G.

[94] Y.P. Dong, Y. Zhou, J. Wang, J.J. Zhu, Electrogenerated chemiluminescence resonance energy transfer between ru(Bpy) 3 2+ electrogenerated chemiluminescence and gold nanoparticles/graphene oxide nanocomposites with graphene oxide as coreactant and its sensing application. Anal. Chem. 2016, 88(10):5469-5475.acs.analchem.6b00921. doi:10.1021/acs.analchem.6b00921.

[95] J. Wang, Y. Shan, W.-W. Zhao, J.-J. Xu, H.-Y. Chen, Gold nanoparticle enhanced electrochemiluminescence of CdS thin films for ultrasensitive thrombin detection, Anal. Chem. 83 (11) (2011) 4004–4011, doi:10.1021/ac200616g.

[96] P. Perez-Tejeda, E. Grueso, A. Marin-Gordillo, C. Torres-Marquez, R.M. Giráldez-Pérez, Aqueous gold nanoparticle solutions for improved efficiency in electrogenerated chemiluminescent reactions, ACS Appl. Nano Mater. 1 (9) (2018) 5307–5315, doi:10.1021/acsanm.8b01323.

[97] G. Schmid, M. Bäumle, M. Geerkens, I. Heim, C. Osemann, T. Sawitowski, Current and future applications of nanoclusters, Chem. Soc. Rev. 28 (3) (1999) 179–185, doi:10.1039/A801153B.

[98] Y. Zou, H. Zhang, Z. Wang, Q. Liu, Y. Liu, A novel ECL method for histone acetyltransferases (HATs) activity analysis by integrating HCR signal amplification and ECL silver clusters, Talanta 198 (2019) 39–44, doi:10.1016/j.talanta.2019.01.083.

[99] L. Li, H. Liu, Y. Shen, J. Zhang, J.-J. Zhu, Electrogenerated chemiluminescence of Au nanoclusters for the detection of dopamine, Anal. Chem. 83 (3) (2011) 661–665, doi:10.1021/ac102623r.

[100] F. Yang, X. Zhong, X. Jiang, Y. Zhuo, R. Yuan, S. Wei, An ultrasensitive aptasensor based on self-enhanced au nanoclusters as highly efficient electrochemiluminescence indicator and multi-site landing DNA walker as signal amplification, Biosens. Bioelectron. 130 (2019) 262–268, doi:10.1016/j.bios.2019.01.057.

[101] Y. Yuan, L. Zhang, H. Wang, Y. Chai, R. Yuan, Self-enhanced PEI-Ru(II) complex with polyamino acid as booster to construct ultrasensitive electrochemiluminescence immunosensor for carcinoembryonic antigen detection, Anal. Chim. Acta 1001 (2018) 112–118, doi:10.1016/j.aca.2017.11.035.

[102] L. Ma, N. Wu, Y. Liu, X. Ran, D. Xiao, Self-electrochemiluminescence of Poly[9,9-B*is*(3‘-(N,N- D*imethyl* A*mino*)P*ropyl*)-2,7-F*luorene*]-Alt- 2,7-(9,9- Dioctylfluorene)] and resonance energy transfer to aluminum tris(8-Quinolinolate), Electrochim. Acta 297 (2019) 826–832, doi:10.1016/j.electacta.2018.12.046.

[103] W. Liang, Y. Zhuo, C. Xiong, Y. Zheng, Y. Chai, R. Yuan, Ultrasensitive cytosensor based on self-enhanced electrochemiluminescent ruthenium-silica composite nanoparticles for efficient drug screening with cell apoptosis monitoring, Anal. Chem. 87 (24) (2015) 12363–12371, doi:10.1021/acs.analchem.5b03822.

[104] G.-F. Gui, Y. Zhuo, Y.-Q. Chai, Y. Xiang, R. Yuan, In situ generation of self-enhanced luminophore by β-lactamase catalysis for highly sensitive electrochemiluminescent aptasensor, Anal. Chem. 86 (12) (2014) 5873–5880, doi:10.1021/ac500665b.

[105] S. Kesarkar, S. Valente, A. Zanut, F. Palomba, A. Fiorani, M. Marcaccio, E. Rampazzo, G. Valenti, F. Paolucci, L. Prodi, Neutral dye-doped silica nanoparticles for electrogenerated chemiluminescence signal amplification, J. Phys. Chem. C 123 (9) (2019) 5686–5691, doi:10.1021/acs.jpcc.8b11049.
[106] X. Lv, M. Li, Z. Guo, X. Zheng, Electrochemiluminescence observing the surface features of ru-doped silica nanoparticles based on nanoparticle–ultramicroelectrode collision, Luminescence 34 (3) (2019) 334–340, doi:10.1002/bio.3611.
[107] J. Sun, H. Sun, Z. Liang, Nanomaterials in electrochemiluminescence sensors, Chem. Electro. Chem. 4 (7) (2017) 1651–1662, doi:10.1002/celc.201600920.
[108] L. Zhang, S. Dong, Electrogenerated chemiluminescence sensors using ru(Bpy)32+ doped in silica nanoparticles, Anal. Chem. 78 (14) (2006) 5119–5123, doi:10.1021/ac060451n.
[109] G.D. Storrier, K. Takada, H.D. Abruña, Synthesis, characterization, electrochemistry, and EQCM studies of polyamidoamine dendrimers surface-functionalized with polypyridyl metal complexes, Langmuir 15 (3) (1999) 872–884, doi:10.1021/la980939m.
[110] M. Zhou, J. Roovers, Dendritic supramolecular assembly with multiple ru(II) tris(Bipyridine) units at the periphery: synthesis, spectroscopic, and electrochemical study, Macromolecules 34 (2) (2001) 244–252, doi:10.1021/ma001463s.
[111] F. Sun, Z. Wang, Y. Feng, Y. Cheng, H. Ju, Y. Quan, Electrochemiluminescent resonance energy transfer of polymer dots for aptasensing, Biosens. Bioelectron. 100 (2018) 28–34, doi:10.1016/j.bios.2017.08.047.
[112] Y. Fang, Z. Wang, Y. Li, Y. Quan, Y. Cheng, The amplified electrochemiluminescence response signal promoted by the ir(Iii)-containing polymer complex, Analyst 143 (10) (2018) 2405–2410, doi:10.1039/C8AN00426A.
[113] W. Guo, H. Ding, B. Su, Electrochemiluminescence of metallated porous organic polymers, J. Electroanal. Chem. 818 (2018) 176–180, doi:10.1016/j.jelechem.2018.04.037.
[114] S. Carrara, A. Aliprandi, C.F. Hogan, L. De Cola, Aggregation-induced electrochemiluminescence of platinum(II) complexes, J. Am. Chem. Soc. 139 (41) (2017) 14605–14610, doi:10.1021/jacs.7b07710.
[115] X. Wei, M.J. Zhu, Z. Cheng, M. Lee, H. Yan, C. Lu, J.J. Xu, Aggregation-induced electrochemiluminescence of carboranyl carbazoles in aqueous media, Angew. Chemie - Int. Ed. 58 (10) (2019) 3162–3166, doi:10.1002/anie.201900283.
[116] M.H. Jiang, S.K. Li, X. Zhong, W.B. Liang, Y.Q. Chai, Y. Zhuo, R. Yuan, Electrochemiluminescence enhanced by restriction of intramolecular motions (RIM): tetraphenylethylene microcrystals as a novel emitter for mucin 1 detection, Anal. Chem. 91 (5) (2019) 3710–3716, doi:10.1021/acs.analchem.8b05949.
[117] M.M. Chen, Y. Wang, S.B. Cheng, W. Wen, X. Zhang, S. Wang, W.H Huang, Construction of highly efficient resonance energy transfer platform inside a nanosphere for ultrasensitive electrochemiluminescence detection, Anal. Chem. 90 (8) (2018) 5075–5081, doi:10.1021/acs.analchem.7b05074.
[118] S. Xu, Y. Liu, T. Wang, J. Li, Positive potential operation of a cathodic electrogenerated chemiluminescence immunosensor based on luminol and graphene for cancer biomarker detection, Anal. Chem. 83 (10) (2011) 3817–3823, doi:10.1021/ac200237j.
[119] G. Jie, J. Zhang, D. Wang, C. Cheng, H.-.Y. Chen, J.-.J. Zhu, Electrochemiluminescence immunosensor based on CdSe nanocomposites, Anal. Chem. 80 (11) (2008) 4033–4039, doi:10.1021/ac800052g.

[120] G.F. Jie, B. Liu, J.J. Miao, J.J. Zhu, Electrogenerated Chemiluminescence from CdS nanotubes and its sensing application in aqueous solution, Talanta 71 (4) (2007) 1476–1480, doi:10.1016/j.talanta.2006.07.029.

[121] Y. Zhang, J. Xu, J. Xia, F. Zhang, Z. Wang, MOF-derived porous Ni2P/graphene composites with enhanced electrochemical properties for sensitive nonenzymatic glucose sensing, ACS Appl. Mater. Interfaces 10 (45) (2018) 39151–39160, doi:10.1021/acsami.8b11867.

[122] Y.T. Zholudov, G. Xu, Electrogenerated chemiluminescence at a 9,10-diphenylanthracene/polyvinyl butyral film modified electrode with a tetraphenylborate coreactant, Analyst 143 (14) (2018) 3425–3432, doi:10.1039/c8an00889b.