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面向细胞的金属纳米薄膜介导荧光技术

Metallic Nanofilm Mediated Fluorescence Techniques for Cell Research

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摘　要

金属纳米薄膜具有调控荧光团发光性质的特点，吸引了越来越多研究者的关注。它主要通过两种方式对荧光团的发光性质进行调控。1）金属纳米薄膜表面的等离子体与荧光团发生耦合，使之发射高度定向的、偏振的荧光信号，产生表面等离子体耦合发射荧光（Surface Plasmon Coupled Emission，SPCE）。由于表面等离子体共振（SPR）模式和等离子体波导共振（PWR）模式的存在，SPCE技术的耦合距离可从纳米级拓展到微米量级，在微米级尺度样品的研究中展现出应用潜力。2）金属纳米薄膜反射激发光和发射光，反射光束与原光束发生干涉，产生镜面效应，从而改变荧光团的发光强度、荧光寿命和发射空间分布。镜面效应具有远场特性，可在微米级尺度范围内增强荧光信号，有望提高细胞荧光成像的灵敏度和对比度。本论文致力于发展面向细胞的金属纳米薄膜介导的荧光技术，共六章：

第一章 绪论。该章首先阐述了平滑金属纳米薄膜镜面效应增强荧光的原理、研究进展及其在细胞荧光成像中的应用；而后重点介绍了SPCE的原理和光学特性，概述了SPCE在机理研究、基底和样品尺度拓展、生化传感及显微成像等方面的研究进展。

第二章 探索了平滑金纳米薄膜对细胞荧光成像增强作用的距离效应。从荧光强度和荧光寿命两个方面系统地考察了平滑金纳米薄膜对细胞荧光成像增强作用的距离效应。基底侧、界面处和样品侧均能观察到荧光增强细胞成像。不同物镜条件下观察到不同的距离效应：当物镜数值孔径较小时，荧光增强因子不随距离发生明显变化；当物镜数值孔径较大时，基底侧荧光增强因子随距离增大而增大，而细胞侧荧光增强因子则随距离增大而减小。平滑金纳米薄膜对荧光寿命的影响也具有距离效应，与细胞深处相比，界面处细胞荧光寿命明显缩短。此外，还考察了染色层厚度和发射光波长对荧光增强作用的影响。本章为制备简单、使用方便、具有均一增强效果的平滑金属纳米薄膜在细胞荧光成像的应用推广提供了便利。

第三章 研究了从纳米到微米范围内样品尺度与SPCE性质的相关性。考察了空气体系Au膜和Al膜两种基底上SPCE性质与样品厚度的相关性，当样品厚度为几十纳米时，荧光团与表面等离子体以表面等离子体共振（SPR）模式发生耦合；当样品厚度为100 nm到1 µm时，荧光团与表面等离子体以等离子体波导共振（PWR）模式发生耦合。SPR模式和PWR模式SPCE均具有偏振性、角度分辨性和波长分辨性。首次研究了水溶液体系样品厚度对SPCE性质的影响，观察到与空气体系类似的变化规律。当样品厚度大于1 µm时，水溶液体系SPCE荧光信号仍具有偏振性和角度分辨性。SPCE技术在样品厚度测定、细胞研究等领域展现出应用前景。

第四章 探究了染色细胞的SPCE性质。利用反Kretschmann模式SPCE光谱系统地研究了Au膜基底上不同亚区荧光标记细胞的SPCE现象。细胞膜、细胞质和细胞核染色细胞的SPCE信号均具有明显的偏振性和角度分辨性。通过细胞密度实验和PMMA模拟实验探究了微米级尺度下样品厚度与SPCE性质之间的关系，发现了两者间新的变化规律：SPCE信号始终具有部分p-偏振性，不随样品厚度增大而发生偏振逆转；最大发射角度几乎不随样品厚度、染料层厚度、发射光波长的变化而变化。探讨了金属基底种类对细胞SPCE性质的影响，Al膜基底表现出最好的SPCE特性。此外，利用SPCE实现了细胞染色过程的实时在线检测。本章为SPCE技术在细胞膜流动性、细胞内生物分子间相互作用、细胞分区检测中的应用提供了基础。

第五章 初步探索了具有偏振调控功能的SPCE显微系统的构建。在全内反射荧光显微系统基础上，对激发光偏振性调制，并调节入射光在后焦平面的位置使之满足SPR条件，Au膜基底上可观察到细胞的SPCE荧光显微成像。与全内反射荧光成像相比，荧光强度增大且具有SPCE特征的角度分辨性。初步探索了不同金属基底的细胞SPCE显微成像，30 nm Au膜适合于细胞SPCE成像研究。实验结果表明，激发光合理的偏振取向和波长以及合适的金属基底是实现细胞SPCE成像的关键。此外，若对发射光进行检偏，纯化SPCE信号，有望提高细胞成像的SPCE特性。本章为SPCE显微系统的构建和性能提高指引了方向。

第六章 结语与展望。总结了本论文研究工作的创新性，并对研究工作的进一步开展进行了展望。

关键词：表面等离子体耦合发射荧光；镜面效应；平滑金属纳米薄膜荧光增强作用；细胞；表面等离子体耦合发射荧光显微系统

Abstract

Metallic nanofilms have attracted more and more attention owing to their characteristics in engineering the emission properties of fluorophores. Generally, there are two manners of engineering: the first is surface plasmon coupled emission (SPCE). The excited fluorophores couple with surface plasmons on metal surface and result in highly directional and polarized emission. The coupling distance of SPCE is extended from nanoscale to micrometer-scale because of the coaction of surface plasmon resonance (SPR) mode and plasmon waveguide resonance (PWR) mode. Thus, SPCE holds great potential to study micrometer-scale samples such as cells. The second is mirror effect of metallic nanofilms. The excitation light and emission light are reflected by the metallic nanofilms, leading to standing waves, which can change the excitation efficiency, radiation rate and emission pattern of fluorophores. Mirror effect has advantages in improving the sensitivity and contrast of cell imaging because of its far-field fluorescence enhancement in micrometer-scale. This dissertation focuses on metallic nanofilm mediated fluorescence techniques for cells. It consists of six chapters.

In the first chapter, a literature survey was presented. First, the principle and research progress of fluorescence enhancement based on mirror effect of smooth metallic nanofilm, and its application in cell imaging were reviewed. Second, the principle and characteristics of SPCE were introduced. Then, the development of its mechanism, the exploration of metallic substrates and sample size, and the applications in biosensor and microscopy were reviewed.

In the second chapter, the distance dependence of fluorescence enhancement based on mirror effect of smooth metallic nanofilms in cell imaging was explored. We studied the distance dependence of fluorescence intensity and lifetime in cell imaging on Au substrates. Enhancement was observed inside cells, near metal

surface, even inside the metallic substrate because of the enhanced reflection images based on the mirror effect. Different types of objectives showed different distance dependence of enhancement factors. For a low numerical aperture (NA) objective, enhancement factors almost stayed at the same level with the increase of imaging depth into either cell or substrate. While for a high NA objective, the enhancement factor increased with the increase of imaging depth in the substrate, but decreased in cell. Fluorescence lifetime also exhibited distance-dependent behavior. The lifetime of cell images near metal surface was greatly reduced, in contrast to those inside the cell. Moreover, we also investigated the impact of dye distribution and emission wavelength on the enhancement of fluorescence. Our study provided a basis to wide application of easy-accessed and convenient smooth metallic nanofilms with uniform fluorescence enhancement effect for cell imaging.

In the third chapter, the impact of sample thickness on SPCE properties was investigated. First, we studied the relationship between sample thickness and SPCE properties of Au substrate and Al substrate in air. Fluorophores coupled with surface plasmons via surface plasmon resonance (SPR) mode when sample thickness was in dozens of nanometers. While in hundreds of nanometers, they were coupled via plasmon waveguide resonance (PWR) mode. Both coupling modes of SPCE exhibited unique polarization, angle distribution and wavelength distribution. Second, their relationship in water was studied for the first time. It turned out to be similar to that in air. Interestingly, in water, SPCE signal still had polarization and angle distribution while sample thickness was larger than 1 m. Our studies demonstrated that this technique can be used in sample thickness detection and cell research.

In the fourth chapter, SPCE properties of cell were investigated. SPCE properties of cells labeled in different subregions were studied using a reverse Kretschmann (RK) configuration SPCE spectroscopy system. Angular and p-polarized emission

was observed for cells labeled in membrane, cytoplasm and nucleus. For micrometer-scale samples, new SPCE behaviors were expected. The SPCE signals were always partially p-polarized and the maximum emission angle did not shift, regardless of the variation in emission wavelength, fluorophore distribution and stained layers thickness. We also investigated the impact of metallic substrates on SPCE properties of cell. Compared with Au and Ni substrates, Al substrate presented better performances in polarization and angle distribution. Moreover, the real-time detection of the cell labeling process was achieved by monitoring SPCE intensity. These findings provide a basis to apply SPCE technique to study cell membrane fluidity and biomolecule interactions inside the cell and to distinguish between cellular subregions.

In the fifth chapter, the establishment of SPCE microscope with the control of the polarization of excitation light was investigated preliminarily. A total internal reflection fluorescence (TIRF) microscope was derived to SPCE microscope with the modulation of the polarization and illumination position of excitation light. Compared with TIRF images, the intensity of SPCE images was greatly enhanced. The SPCE imaging of cell with different metallic substrates was also investigated. It was found that 30 nm of Au film was the suitable substrate for cell imaging. Experiment results showed that appropriate metallic substrate and excitation light with appropriate polarization and wavelength were the key to achieve SPCE imaging in cells. Moreover, the SPCE properties of cell images can be improved via setting polarizer before use detector to purify signal. Our findings provide a basis to establish a SPCE microscope and improve its performance.

In the sixth chapter, the innovative aspects were discussed and the prospect of this research was pointed out.

Keywords: Surface plasmon coupled emission; Mirror effect; Fluorescence enhancement on smooth metallic nanofilms; Cell; Surface plasmon coupled emission microscope

参考资料

[1]Fermi E. Quantum theory of radiation[J]. Rev Mod Phys, 1932,4: 87-132.
[2]Selenyi P. Production and properties of wide-angle optical interference phenomena[J]. Z Phys, 1938,108: 401-407.
[3]Drexhage KH. Multiphoton excitation of fluorescence in standing light waves and measurement of picosecond pulses[J]. Appl Phys Lett, 1969,14: 318-320.
[4]Drexhage KH. Influence of a dielectric interface on fluorescence decay time. 1970[C]. North-Holland Publ. Co.
[5]Drexhage KH. Monomolecular layers and light[J]. Sci Amer, 1970,222: 108-119.
[6]Tews KH, Inacker O and Kuhn H. Variation of the luminescence lifetime of a molecule near an interface between differently polarizable dielectrics[J]. Nature, 1970,228: 276-278.
[7]Drexhage KH. Interaction of light with monomolecular dye layers[J]. Prog Opt, 1974,12: 163-232.
[8]Chance RR, Prock A and Silbey R. Classical theory of energy transfer[J]. J Chem Phys, 1975,62: 2245-2253.
[9]Chance RR, Prock A and Silbey R. Lifetime of an emitting molecule near a partially reflecting surface[J]. J Chem Phys, 1974,60: 2744-2748.
[10] Chance RR, Prock A and Silbey R. Lifetime of an excited molecule near a metal mirror. Energy transfer in the europium (3+)/silver system[J]. J Chem Phys, 1974,60: 2184-2185.
[11] Chance RR, Miller AH, Prock A and Silbey R. Luminescent lifetimes near multiple interfaces. Quantitative comparison of theory and experiment[J]. Chem Phys Lett, 1975,33: 590-592.
[12] Chance RR, Miller AH, Prock A and Silbey R. Fluorescence and energy transfer near interfaces. Complete and quantitative description of the europium(3+) ion/mirror (Eu3+/mirror) systems[J]. J Chem Phys, 1975,63: 1589-1595.
[13] Chance RR, Prock A and Silbey R. Frequency shifts of an electric-dipole transition near a partially reflecting surface[J]. Phys Rev A, 1975,12: 1448-1452.
[14] Chance RR, Prock A and Silbey R. Decay of an emitting dipole between two parallel mirrors[J]. J Chem Phys, 1975,62: 771-772.
[15] Chance RR, Prock A and Silbey R. Molecular fluorescence and energy transfer near interfaces[J]. Adv Chem Phys, 1978,37: 1-65.
[16] Ford GW and Weber WH. Electromagnetic interactions of molecules with metal surfaces[J]. Phys Rep, 1984,113: 195-287.
[17] Waldeck DH, Alivisatos AP and Harris CB. Nonradiative damping of molecular electronic excited states by metal surfaces[J]. Surf Sci, 1985,158: 103-125.
[18] Barnes WL. Fluorescence near interfaces: the role of photonic mode density[J]. J Mod Opt, 1998,45: 661-699.
[19] Amos RM and Barnes WL. Modification of the spontaneous emission rate of Eu3+ ions close to a thin metal mirror[J]. Phys Rev B: Condens Matter, 1997,55: 7249-7254.
[20] Weber WH and Eagen CF. Energy transfer from an excited dye molecule to the surface plasmons of an adjacent metal[J]. Opt Lett, 1979,4: 236-238.
[21] Pockrand I, Brillante A and Moebius D. Nonradiative decay of excited molecules near a metal surface[J]. Chem Phys Lett, 1980,69: 499-504.
[22] Lukosz W and Kunz RE. New method for determining refractive index and thickness of fluorescent thin films[J]. Opt Commun, 1979,31: 251-256.
[23] Cnossen G, Drabe KE and Wiersma DA. Fluorescence properties of submonolayers of Rhodamine 6G in front of a mirror[J]. J Chem Phys, 1993,98: 5276-5280.
[24] Adams A, Rendell RW, West WP, Broida HP, Hansma PK and Metiu H. Luminescence and nonradiative energy transfer to surfaces[J]. Phys Rev B: Condens Matter, 1980,21: 5565-5571.

[25] Adams A, Moreland J and Hansma PK. Angular resonances in the light emission from atoms near a grating[J]. Surf Sci, 1981,111: 351-357.
[26] Knoll W, Philpott MR, Swalen JD and Girlando A. Emission of light from silver metal gratings coated with dye monolayer assemblies[J]. J Chem Phys, 1981,75: 4795-4799.
[27] Holland WR and Hall DG. Waveguide mode enhancement of molecular fluorescence[J]. Opt Lett, 1985,10: 414-416.
[28] Sullivan KG and Hall DG. Enhancement and inhibition of electromagnetic radiation in plane-layered media. II. Enhanced fluorescence in optical waveguide sensors[J]. J Opt Soc Am B, 1997,14: 1160-1166.
[29] Sullivan KG and Hall DG. Enhancement and inhibition of electromagnetic radiation in plane-layered media. I. Plane-wave spectrum approach to modeling classical effects[J]. J Opt Soc Am B, 1997,14: 1149-1159.
[30] Worthing PT, Amos RM and Barnes WL. Modification of the spontaneous emission rate of Eu3+ ions embedded within a dielectric layer above a silver mirror[J]. Phys Rev A: At, Mol, Opt Phys, 1999,59: 865-872.
[31] Andrew P and Barnes WL. Forster energy transfer in an optical microcavity[J]. Science, 2000,290: 785-788.
[32] Wasey JAE, Safonov A, Samuel IDW and Barnes WL. Effects of dipole orientation and birefringence on the optical emission from thin films[J]. Opt Commun, 2000,183: 109-121.
[33] Andrew P and Barnes WL. Molecular fluorescence above metallic gratings[J]. Phys Rev B: Condens Matter Mater Phys, 2001,64: 125405/1-11.
[34] Giannattasio A, Wedge S and Barnes WL. Role of surface profiles in surface plasmon-polariton-mediated emission of light through a thin metal film[J]. J Mod Opt, 2006,53: 429-436.
[35] Barnes WL and Worthing PT. Spontaneous emission and metal-clad microcavities[J]. Opt Commun, 1999,162: 16-20.
[36] Garrett SH, Wasey JAE and Barnes WL. Determining the orientation of the emissive dipole moment associated with dye molecules in microcavity structures[J]. J Mod Opt, 2004,51: 2287-2295.
[37] Hobson PA, Barnes WL, Lidzey DG, Gehring GA, Whittaker DM, Skolnick MS, and Walker S. Strong exciton-photon coupling in a low-Q all-metal mirror microcavity[J]. Appl Phys Lett, 2002,81: 3519-3521.
[38] Salt MG and Barnes WL. Flat photonic bands in guided modes of textured metallic microcavities[J]. Phys Rev B: Condens Matter Mater Phys, 2000,61: 11125-11135.
[39] Salt MG, Tan WC and Barnes WL. Photonic band gaps and flat band edges in periodically textured metallic microcavities[J]. Appl Phys Lett, 2000,77: 193-195.
[40] Worthing PT, Wasey JAE and Barnes WL. Rate and efficiency of spontaneous emission in metal-clad microcavities[J]. J Appl Phys, 2001,89: 615-625.
[41] Barnes WL, Preist TW, Kitson SC and Sambles JR. Physical origin of photonic energy gaps in the propagation of surface plasmons on gratings[J]. Phys Rev B: Condens Matter, 1996,54: 6227-6244.
[42] Barnes WL, Preist TW, Kitson SC, Sambles JR, Cotter NPK and Nash DJ. Photonic gaps in the dispersion of surface plasmons on gratings[J]. Phys Rev B: Condens Matter, 1995,51: 11164-11167.
[43] Kitson SC, Barnes WL, Bradberrt GW and Sambles JR. Surface profile dependence of surface plasmon band gaps on metallic gratings[J]. J Appl Phys, 1996,79: 7383-7385.
[44] Kitson SC, Barnes WL and Sambles JR. Photoluminescence from dye molecules on silver gratings[J]. Opt Commun, 1996,122: 147-154.
[45] Worthing PT and Barnes WL. Efficient coupling of surface plasmon polaritons to radiation using a bi-grating[J]. Appl Phys Lett, 2001,79: 3035-3037.
[46] Mangeat T, Berthier A, Elie-Caille C, Perrin M, Boireau W, Pieralli C and Wacogne B. Gold/Silica biochips: Applications to Surface Plasmon Resonance and fluorescence quenching[J]. Laser Phys, 2009,19: 252-258.
[47] Akimoto T and Yasuda M. Fluorescence enhancement and reflection of the excitation light observed with a multilayered substrate[J]. Appl Opt, 2010,49: 80-85.
[48] Le Moal E, Fort E, Leveque-Fort S, Cordelieres FP, Fontaine-Aupart MP and Ricolleau C. Enhanced fluorescence cell imaging with metal-coated slides[J]. Biophys J, 2007,92(6): 2150-2161.
[49] Moal E, Fort E, Leveque-Fort S, Janin A, Murata H, Cordelieres FP, Fontaine-Aupart MP and Ricolleau C.

Mirror slides for high-sensitivity cell and tissue fluorescence imaging[J]. J Biomed Opt, 2007,12(2).
[50] Cade NI, Fruhwirth G, Archibald SJ, Ng T and Richards D. A cellular screening assay using analysis of metal-modified fluorescence lifetime[J]. Biophys J, 2010,98: 2752-2757.
[51] Matveeva EG, Gryczynski I, Barnett A, Leonenko Z, Lakowicz JR and Gryczynski Z. Metal particle-enhanced fluorescent immunoassays on metal mirrors[J]. Anal Biochem, 2007,363: 239-245.
[52] Sorensen TJ, Laursen BW, Luchowski R, Shtoyko T, Akopova I, Gryczynski Z and Gryczynski I. Enhanced fluorescence emission of Me-ADOTA+ by self-assembled silver nanoparticles on a gold film[J]. Chem Phys Lett, 2009,476: 46-50.
[53] Lakowicz JR, Malicka J, Gryczynski Iand Gryczynski Z. Directional surface plasmon-coupled emission: a new method for high sensitivity detection[J]. Biochem Biophys Res Commun, 2003,307: 435-439.
[54] Lakowicz JR. Radiative decay engineering 3. Surface plasmon-coupled directional emission[J]. Anal Biochem, 2004,324(2): 153-169.
[55] Gryczynski I, Malicka J, Gryczynski Z and Lakowicz JR. Radiative decay engineering 4. Experimental studies of surface plasmon-coupled directional emission[J]. Anal Biochem, 2004,324(2): 170-182.
[56] Aslan K and Geddes CD. Directional Surface Plasmon Coupled Luminescence for Analytical Sensing Applications: Which Metal, What Wavelength, What Observation Angle?[J]. Anal Chem, 2009,81: 6913-6922.
[57] Cao SH, Cai WP, Liu Q and Li YQ. Surface Plasmon-Coupled Emission: What Can Directional Fluorescence Bring to the Analytical Sciences?[J]. Ann Rev Anal Chem, 2012,5: 317-336.
[58] Geddes CD, Gryczynski I, Malicka J, Gryczynski Z and Lakowicz JR. Directional surface plasmon coupled emission[J]. J Fluoresc, 2004,14: 119-123.
[59] Gryczynski I, Malicka J, Gryczynski Z and Lakowicz JR. Surface Plasmon-Coupled Emission with Gold Films[J]. J Phys Chem B, 2004,108: 12568-12574.
[60] Raether H. Surface plasma oscillations and their applications[J]. Phys Thin Films, 1977,9: 145-261.
[61] Haes AJ and Van Duyne RP. A unified view of propagating and localized surface plasmon resonance biosensors[J]. Anal Bioanal Chem, 2004,379: 920-930.
[62] Kretschmann E and Raether H. Radiative decay of nonradiative surface plasmons excited by light[J]. Z Naturforsch A, 1968,23: 2135-2136.
[63] Loefaas S, Malmqvist M, Roennberg I, Stenberg E, Liedberg B and Lundstroem I. Bioanalysis with surface plasmon resonance[J]. Sens Actuators, B, 1991,5: 79-84.
[64] Malmqvist M. Surface plasmon resonance for detection and measurement of antibody-antigen affinity and kinetics[J]. Curr Opin Immunol, 1993,5: 282-286.
[65] Davies J. Surface plasmon resonance-the technique and its applications to biomaterial processes[J]. Nanobiology, 1994,3: 5-16.
[66] Otto A. Excitation of nonradiative surface plasma waves in silver by the method of frustrated total reflection[J]. Z Phys, 1968,216: 398-410.
[67] Lakowicz JR. Radiative Decay Engineering: Biophysical and Biomedical Applications[J]. Anal Biochem, 2001,298(1): 1-24.
[68] Lakowicz JR, Ray K, Chowdhury M, Szmacinski H, Fu Y, Zhang J and Nowaczyk K. Plasmon-controlled fluorescence: a new paradigm in fluorescence spectroscopy[J]. Analyst, 2008,133: 1308-1346.
[69] Chowdhury MH, Malyn SN, Aslan K, Lakowicz, JR and Geddes CD. First observation of surface plasmon-coupled chemiluminescence (SPCC)[J]. Chem Phys Lett, 2007,435(1-3): 114-118.
[70] Zhang J, Gryczynski Z and Lakowicz JR. First observation of surface plasmon-coupled electrochemiluminescence[J]. Chem Phy Lett, 2004,393(4-6): 483-487.
[71] Hiep HM, Fujii M and Hayashi S. Effects of molecular orientation on surface-plasmon-coupled emission patterns[J]. Appl Phys Lett, 2007,91(18): 183110.
[72] Penninck L, Mladenowski S and Neyts K. The effects of planar metallic interfaces on the radiation of nearby electrical dipoles[J]. J Opt, 2010,12: 075001/1-8.
[73] Fort E and Gresillon S. Surface enhanced fluorescence[J]. J Phys D: Appl Phys, 2008,41: 013001/1-31.

[74] Toma K, Vala M, Adam P, Homola J, Knoll W and Dostalek J. Compact surface plasmon-enhanced fluorescence biochip[J]. Opt Express, 2013,21: 10121-10132.
[75] Chi YS, Byon HR, Lee BS, Kong B, Choi HC and Choi IS. Polymeric rulers: distance-dependent emission behaviors of fluorophores on flat gold surfaces and bioassay platforms using plasmonic fluorescence enhancement[J]. Adv Funct Mater, 2008,18: 3395-3402.
[76] Ray K, Szmacinski H, Enderlein J and Lakowicz JR. Distance dependence of surface plasmon-coupled emission observed using Langmuir-Blodgett films[J]. Appl Phys Lett, 2007,90: 251116/1-3.
[77] Xie TT, Liu Q, Cai WP, Chen Z, and Li YQ. Surface plasmon-coupled directional emission based on a conformational-switching signaling aptamer[J]. Chem Commun, 2009: 3190-3192.
[78] Cao SH, Xie TT, Cai WP, Liu Q, and Li YQ. Electric field assisted surface plasmon-coupled directional emission: An active strategy on enhancing sensitivity for DNA sensing and efficient discrimination of single base mutation[J]. J Am Chem Soc, 2011,133: 1787-1789.
[79] Liu XQ, Liu Q, Xie KX, Cao SH, Cai WP and Li YQ. Surface plasmon-coupled emission of multicolor quantum dots[J]. Huaxue Xuebao, 2012,70: 2220-2225.
[80] Yuk JS, O'Reilly E, Forster RJ, MacCraith BD and McDonagh C. Demonstration of surface plasmon-coupled emission using solid-state electrochemiluminescence[J]. Chem Phys Lett, 2011,513: 112-117.
[81] Chowdhury MH, Malyn SN, Aslan K, Lakowicz, JR and Geddes CD. Multicolor Directional Surface Plasmon-Coupled Chemiluminescence[J]. J Phys Chem B, 2006,110: 22644-22651.
[82] Aslan K, Weisenberg M, Hortle E and Geddes CD. Fixed-angle observation of surface plasmon coupled chemiluminescence from palladium thin films[J]. Appl Phys Lett, 2009,95: 123117/1-3.
[83] Weisenberg M, Aslan K, Hortle E and Geddes CD. Directional surface plasmon coupled chemiluminescence from nickel thin films: Fixed angle observation[J]. Chem Phys Lett, 2009,473: 120-125.
[84] Aslan K and Geddes CD. Surface plasmon coupled chemiluminescence from zinc substrates: Directional chemiluminescence[J]. Appl Phys Lett, 2009,94: 073104/1-3.
[85] Aslan K, Weisenberg M, Hortle E and Geddes CD. Surface plasmon coupled chemiluminescence from iron thin films: directional and approaching fixed angle observation[J]. J Appl Phys, 2009,106: 014313/1-5.
[86] Previte MJR and Geddes CD. Microwave-Triggered Surface Plasmon Coupled Chemiluminescence[J]. J Am Chem Soc, 2007,129: 9850-9851.
[87] Previte MJR, Aslan K, Zhang Y and Geddes CD. Surface plasmon coupled phosphorescence (SPCP)[J]. Chem Phys Lett, 2006,432: 610-615.
[88] Previte MJR, Zhang Y, Aslan K and Geddes CD. Surface plasmon coupled fluorescence from copper substrates[J]. Appl Phys Lett, 2007,91: 151902/1-3.
[89] Ray K, Chowdhury MH and Lakowicz JR. Observation of surface plasmon-coupled emission using thin platinum films[J]. Chem Phys Lett, 2008,465: 92-95.
[90] Gryczynski I, Malicka J, Gryczynski Z, Nowaczyk K and Lakowicz JR. Ultraviolet Surface Plasmon-Coupled Emission Using Thin Aluminum Films[J]. Anal Chem, 2004,76: 4076-4081.
[91] Aslan K, Zhang Y and Geddes CD. Surface Plasmon Coupled Fluorescence in the Visible to Near-Infrared Spectral Regions using Thin Nickel Films: Application to Whole Blood Assays[J]. Anal Chem, 2009,81: 3801-3808.
[92] Cao SH, Xie TT, Cai WP and Li YQ. Observation of surface plasmon-coupled directional fluorescence using thin iron films[J]. Gaodeng Xuexiao Huaxue Xuebao, 2010,31: 61-63.
[93] Yuk JS, MacCraith BD and McDonagh C. Signal enhancement of surface plasmon-coupled emission (SPCE) with the evanescent field of surface plasmons on a bimetallic paraboloid biochip[J]. Biosens Bioelectron, 2011,26: 3213-3218.
[94] Previte MJR, Aslan K, Zhang Y and Geddes CD. Metal-Enhanced Surface Plasmon-Coupled Phosphorescence[J]. J Phys Chem C, 2007,111: 6051-6059.
[95] Aslan K, McDonald K, Previte MJR, Zhang Y and Geddes CD. Silver island nanodeposits to enhance surface plasmon coupled fluorescence from copper thin films[J]. Chem Phys Lett, 2008,464: 216-219.

[96] Gryczynski I, Malicka J, Nowaczyk K, Gryczynski Z and Lakowicz JR. Effects of Sample Thickness on the Optical Properties of Surface Plasmon-Coupled Emission[J]. J Phys Chem B, 2004,108: 12073-12083.
[97] Salamon Z, Brown MF and Tollin G. Plasmon resonance spectroscopy: probing molecular interactions within membranes[J]. Trends Biochem Sci, 1999,24: 213-219.
[98] Tollin G, Salamon Z, Cowell S and Hruby VJ. Plasmon-waveguide resonance spectroscopy: a new tool for investigating signal transduction by G-protein coupled receptors[J]. Life Sci, 2003,73(26): 3307-3311.
[99] Hruby V and Tollin G. Plasmon-waveguide resonance (PWR) spectroscopy for directly viewing rates of GPCR/G-protein interactions and quantifying affinities[J]. Curr Opin Pharmacol, 2007,7(5): 507-514.
[100] Calander N. Surface Plasmon-Coupled Emission and Fabry-Perot Resonance in the Sample Layer: A Theoretical Approach[J]. J Phys Chem B, 2005,109: 13957-13963.
[101] Gryczynski I, Malicka J, Nowaczyk K, Gryczynski Z and Lakowicz JR. Waveguide-modulated surface plasmon-coupled emission of Nile blue in poly(vinyl alcohol) thin films[J]. Thin Solid Films, 2006,510: 15-20.
[102] Malicka J, Gryczynski I, Gryczynski Z and Lakowicz JR. DNA Hybridization Using Surface Plasmon-Coupled Emission[J]. Anal Chem, 2003,75: 6629-6633.
[103] Aslan K, Previte MJR, Zhang Y and Geddes CD. Microwave-accelerated surface plasmon-coupled directional luminescence 2: A platform technology for ultra fast and sensitive target DNA detection in whole blood[J]. J Immunol Methods, 2008,331: 103-113.
[104] Matveeva E, Gryczynski Z, Gryczynski I, Malicka J and Lakowicz JR. Myoglobin immunoassay utilizing directional surface plasmon-coupled emission[J]. Anal Chem, 2004,76: 6287-6292.
[105] Lakowicz JR, Malicka J, Matveeva E, Gryczynski I and Gryczynski Z. Plasmonic technology: Novel approach to ultrasensitive immunoassays[J]. Clin Chem, 2005,51: 1914-1922.
[106] Matveeva EG, Gryczynski Z, Malicka J, Lukomska J, Makowiec S, Berndt KW, Lakowicz JR and Gryczynski I. Directional surface plasmon-coupled emission: Application for an immunoassay in whole blood[J]. Anal Biochem, 2005,344: 161-167.
[107] Matveeva EG, Gryczynski I, Barnett A, Calander N and Gryczynski Z. Red blood cells do not attenuate the SPCE fluorescence in surface assays[J]. Anal Bioanal Chem, 2007,388: 1127-1135.
[108] Aslan K, Malyn SN and Geddes CD. Microwave-Accelerated Surface Plasmon-Coupled Directional Luminescence: Application to fast and sensitive assays in buffer, human serum and whole blood[J]. J Immunol Methods, 2007,323: 55-64.
[109] Yuk JS, Trnavsky M, McDonagh C and MacCraith BD. Surface plasmon-coupled emission (SPCE)-based immunoassay using a novel paraboloid array biochip[J]. Biosens Bioelectron, 2010,25: 1344-1349.
[110] Jin LH, Li SM and Cho YH. Enhanced detection sensitivity of pegylated CdSe/ZnS quantum dots-based prostate cancer biomarkers by surface plasmon-coupled emission[J]. Biosens Bioelectron, 2012,33: 284-287.
[111] Cao SH, Cai WP, Liu Q, Xie KX, Weng YH and Li YQ. Turning on fluorescence by plasmonic assembly with large tunable spacing: a new observation and its biosensing application[J]. Chem Commun, 2014,50: 518-520.
[112] Cao SH, Cai WP, Liu Q, Xie KX, Weng YH, Huo SX, Tian ZQ and Li YQ. Label-Free Aptasensor Based on Ultrathin-Linker-Mediated Hot-Spot Assembly To Induce Strong Directional Fluorescence[J]. J Am Chem Soc, 2014,136: 6802-6805.
[113] Cao SH, Zou ZX, Weng YH, Cai WP, Liu Q and Li YQ. Plasmon-mediated fluorescence with distance independence: From model to a biosensing application[J]. Biosens Bioelectron, 2014,58: 258-265.
[114] Yuk JS, Gibson GN, Rice JM, Guignon EF and Lynes MA. Analysis of immunoarrays using a gold grating-based dual mode surface plasmon-coupled emission (SPCE) sensor chip[J]. Analyst, 2012,137: 2574-2581.
[115] Yuk JS, Guignon EF and Lynes MA. Highly sensitive grating coupler-based surface plasmon-coupled emission (SPCE) biosensor for immunoassay[J]. Analyst, 2013,138: 2576-2582.
[116] Molony RD, Rice JM, Yuk JS, Shetty V, Dey D, Lawrence DA and Lynes MA. Mining the salivary proteome with grating-coupled surface plasmon resonance imaging and surface plasmon coupled emission microarrays[J]. Curr Protoc Toxicol, 2012,Chapter 18: Unit 18.16.11-19.

[117] Rice JM, Stern LJ, Guignon EF, Lawrence DA and Lynes MA. Antigen-specific T cell phenotyping microarrays using grating coupled surface plasmon resonance imaging and surface plasmon coupled emission[J]. Biosens Bioelectron, 2012,31: 264-269.
[118] Smith DS, Kostov Y and Rao G. SPCE-based sensors: Ultrafast oxygen sensing using surface plasmon-coupled emission from ruthenium probes[J]. Sens Actuators, B, 2007,127: 432-440.
[119] Chiu NF, Huang TY, Kuo CC, Lin CW and Lee JH. Organic-based plasmonic emitters for sensing applications[J]. Appl Opt, 2013,52: 1383-1388.
[120] Farkas DL, He RY, Chiu KC, Su YD, Chang KL, Chen SJ, Nicolau DV and Leif RC. Study of cell adhesion and migration by using a plasmon-enhanced total internal reflection fluorescence microscope[J]. Proc SPIE, 2006,6088: 608802/1-8.
[121] He RY, Chang GL, Wu HL, Lin CH, Chiu KC, Su YD and Chen SJ. Enhanced live cell membrane imaging using surface plasmon-enhanced total internal reflection fluorescence microscopy[J]. Opt Express, 2006,14: 9307-9316.
[122] He RY, Lin CY, Su YD, Chiu KC, Chang NS, Wu HL and Chen SJ. Imaging live cell membranes via surface plasmon-enhanced fluorescence and phase microscopy[J]. Opt Express, 2010,18: 3649-3659.
[123] He RY, Su YD, Cho KC, Lin CY, Chang NS, Chang CH and Chen SJ. Surface plasmon-enhanced two-photon fluorescence microscopy for live cell membrane imaging[J]. Opt Express, 2009,17: 5987-5997.
[124] Borejdo J, Gryczynski Z, Calander N, Muthu P and Gryczynski I. Application of Surface Plasmon Coupled Emission to Study of Muscle[J]. Biophys J, 2006,91(7): 2626-2635.
[125] Burghardt TP, Charlesworth JE, Halstead MF, Tarara JE and Ajtai K. In Situ Fluorescent Protein Imaging with Metal Film-Enhanced Total Internal Reflection Microscopy[J]. Biophys J, 2006,90(12): 4662-4671.
[126] Gryczynski Z, Borejdo J, Calander N, Matveeva EG. and Gryczynski I. Minimization of detection volume by surface-plasmon-coupled emission[J]. Anal Biochem, 2006,356(1): 125-131.
[127] Cai WP, Liu Q, Cao SH, Weng YH, Liu XQ and Li YQ. Prism-Based Surface Plasmon Coupled Emission Imaging[J]. ChemPhysChem, 2012,13: 3848-3851.
[128] Yuk JS, McDonagh C and MacCraith BD. Demonstration of a surface plasmon-coupled emission (SPCE)-based immunoassay in the absence of a spacer layer[J]. Anal Bioanal Chem, 2010,398: 1947-1954.
[129] Tang WT, Chung E, Kim YH, So PTC and Sheppard CJR. Investigation of the point spread function of surface plasmon-coupled emission microscopy[J]. Opt Express, 2007,15: 4634-4646.
[130] Tang WT, Chung E, Kim Y, So PTC and Sheppard CJR. Effects of using a metal layer in total internal reflection fluorescence microscopy[J]. Appl Phys A: Mater Sci Process, 2007,89: 333-335.
[131] Tang WT, Chung E, Kim Y-H, So PTC and Sheppard CJR. Surface-plasmon-coupled emission microscopy with a spiral phase plate[J]. Opt Lett, 2010,35: 517-519.
[132] Chen Y, Zhang D, Han L, Rui G., Wang X, Wang P and Ming H. Surface-plasmon-coupled emission microscopy with a polarization converter[J]. Opt Lett, 2013,38: 736-738.
[133] Hohenau A, Krenn JR, Stepanov AL, Drezet A, Ditlbacher H, Steinberger B, Leitner A and Aussenegg FR. Dielectric optical elements for surface plasmons[J]. Opt Lett, 2005,30: 893-895.
[134] Zhang D, Yuan X and Bouhelier A. Direct image of surface-plasmon-coupled emission by leakage radiation microscopy[J]. Appl Opt, 2010,49: 875-879.
[135] Zhang DG, Moh KJ and Yuan XC. Surface plasmon-coupled emission from shaped PMMA films doped with fluorescence molecules[J]. Opt Express, 2010,18: 12185-12190.
[136] Zhang DG, Yuan XC and Teng JH. Surface plasmon-coupled emission on metallic film coated with dye-doped polymer nanogratings[J]. Appl Phys Lett, 2010,97: 231117/1-3.
[137] Borejdo J, Calander N, Gryczynski Z and Gryczynski I. Fluorescence correlation spectroscopy in surface plasmon coupled emission microscope[J]. Opt Express, 2006,14: 7878-7888.
[138] Mettikolla P, Calander N, Luchowski R, Gryczynski I, Gryczynski Z and Borejdo J. Kinetics of a single cross-bridge in familial hypertrophic cardiomyopathy heart muscle measured by reverse Kretschmann fluorescence[J]. J Biomed Opt, 2010,15(1): 017011.

[139] Gryczynski I, Malicka J, Lakowicz JR, Goldys EM, Calander N and Gryczynski Z. Directional two-photon induced surface plasmon-coupled emission[J]. Thin Solid Films, 2005,491: 173-176.
[140] Chiu KC, Lin CY, Dong CY and Chen SJ. Optimizing silver film for surface plasmon-coupled emission induced two-photon excited fluorescence imaging[J]. Opt Express, 2011,19: 5386-5396.
[141] Campagnola PJ, Balaa K, Devauges V, Goulam Y, Studer V, L é v ê que-Fort S, Fort E, Stelzer EHK and von Bally G. Live cell imaging with surface plasmon-mediated fluorescence microscopy[J]. Proc SPIE, 2009,7367: 736710/1-8.
[142] Tawa K, Hori H, Kintaka K, Kiyosue K, Tatsu Y and Nishii J. Optical microscopic observation of fluorescence enhanced by grating-coupled surface plasmon resonance[J]. Opt Express, 2008,16: 9781-9790.
[143] Yasui C, Tawa K, Hosokawa C, Nishii J, Aota H and Matsumoto A. Sensitive fluorescence microscopy of neurons cultured on a plasmonic chip[J]. Jpn J Appl Phys, 2012,51: 06FK10/1-5.
[144]Aslan K, Gryczynski I, Malicka J, Matveeva E, Lakowicz JR and Geddes CD. Metal-enhanced fluorescence: an emerging tool in biotechnology[J]. Curr Opin Biotech, 2005,16(1): 55-62.
[145]Cui Q, He F, Wang X, Xia B and Li L. Gold Nanoflower@Gelatin Core – Shell Nanoparticles Loaded with Conjugated Polymer Applied for Cellular Imaging[J]. ACS Applied Material Interface, 2013,5(1): 213-219.
[146]Deng W and Goldys EM. Plasmonic Approach to Enhanced Fluorescence for Applications in Biotechnology and the Life Sciences[J]. Langmuir, 2012,28(27): 10152-10163.
[147]Mohseni H, Gartia MR, Hsiao A, Sivaguru M, Chen Y, Liu GL, Agahi MH and Razeghi M. Nanoplasmon coupled intracellular optical resonance excitation for ultrasensitive 3D fluorescence cell imaging[J]. Proc SPIE, 2011,8099: 80990T/1-12.
[148]Zhang J, Fu Y, Liang D, Zhao RY and Lakowicz JR. Enhanced fluorescence images for labeled cells on silver island films[J]. Langmuir, 2008,24(21): 12452-12457.
[149]Lin S, Wong MM-K, Pat P-K, Wong CY, Chiu SK and Pun EYB. Cadmium Sulfide Silver Nanoplate Hybrid Structure: Synthesis and Fluorescence Enhancement[J]. J Phys Chem C, 2011,115(44): 21604-21609.
[150]Zhang J, Fu Y, Mei Y, Jiang F and Lakowicz JR. Fluorescent metal nanoshell probe to detect single miRNA in lung cancer cell[J]. Anal Chem, 2010,82(11): 4464-4471.
[151]Drexhage KH. Multiphoton excitation of fluorescence in standing light waves and measurement of picosecond pulses[J]. Appl Phys Lett, 1969,14: 318-320.
[152]Drexhage KH. Influence of a dielectric interface on fluorescence decay time. 1970[C]. North-Holland Publ. Co.
[153] Drexhage KH. Monomolecular layers and light[J]. Sci Amer, 1970,222: 108-119.
[154] Drexhage KH. Interaction of light with monomolecular dye layers[J]. Prog Opt, 1974,12: 163-232.
[155] Chance RR, Prock A and Silbey R. Classical theory of energy transfer[J]. J Chem Phys, 1975,62: 2245-2253.
[156] Chance RR, Miller AH, Prock A and Silbey R. Fluorescence and energy transfer near interfaces. Complete and quantitative description of the europium(3+) ion/mirror (Eu3+/mirror) systems[J]. J Chem Phys, 1975,63: 1589-1595.
[157] Chance RR, Miller AH, Prock A and Silbey R. Luminescent lifetimes near multiple interfaces. Quantitative comparison of theory and experiment[J]. Chem Phys Lett, 1975,33: 590-592.
[158] Chance RR, Prock A and Silbey R. Lifetime of an emitting molecule near a partially reflecting surface[J]. J Chem Phys, 1974,60: 2744-2748.
[159] Chance RR, Prock A and Silbey R. Lifetime of an excited molecule near a metal mirror. Energy transfer in the europium (3+)/silver system[J]. J Chem Phys, 1974,60: 2184-2185.
[160] Chance RR, Prock A and Silbey R. Frequency shifts of an electric-dipole transition near a partially reflecting surface[J]. Phys Rev A, 1975,12: 1448-1452.
[161] Chance RR, Prock A and Silbey R. Molecular fluorescence and energy transfer near interfaces[J]. Adv Chem Phys, 1978,37: 1-65.
[162] Amos RM and Barnes WL. Modification of the spontaneous emission rate of Eu3+ ions close to a thin

metal mirror[J]. Phys Rev B: Condens Matter, 1997,55: 7249-7254.
[163] Barnes WL. Fluorescence near interfaces: the role of photonic mode density[J]. J Mod Opt, 1998,45: 661-699.
[164] Barnes WL and Worthing PT. Spontaneous emission and metal-clad microcavities[J]. Opt Commun, 1999,162: 16-20.
[165] Worthing PT and Barnes WL. Spontaneous emission within metal-clad microcavities[J]. J Opt A: Pure Appl Opt, 1999,1: 501-506.
[166] Garrett SH, Wasey JAE and Barnes WL. Determining the orientation of the emissive dipole moment associated with dye molecules in microcavity structures[J]. J Mod Opt, 2004,51: 2287-2295.
[167] Cao SH, Cai WP, Liu Q and Li YQ. Surface Plasmon-Coupled Emission: What Can Directional Fluorescence Bring to the Analytical Sciences?[J]. Ann Rev Anal Chem, 2012,5: 317-336.
[168] Lakowicz JR. Radiative decay engineering 3. Surface plasmon-coupled directional emission[J]. Anal Biochem, 2004,324(2): 153-169.
[169] Xie TT, Liu Q, Cai WP, Chen Z and Li YQ. Surface plasmon-coupled directional emission based on a conformational-switching signaling aptamer[J]. Chem Commun, 2009: 3190-3192.
[170] Le Moal E, Fort E, Leveque-Fort S, Cordelieres FP, Fontaine-Aupart MP and Ricolleau C. Enhanced fluorescence cell imaging with metal-coated slides[J]. Biophy J 2007,92(6): 2150-2161.
[171] Le Moal E, Leveque-Fort S, Fort E, Lacharme JP, Fontaine-Aupart MP and Ricolleau C. Active substrates improving sensitivity in biomedical fluorescence microscopy[J]. Proc SPIE, 2005,5860: 58600G/1-10.
[172] Moal E, Fort E, Leveque-Fort S, Murata H, Cordelieres FP, Fontaine-Aupart MP and Ricolleau C. Mirror slides for high-sensitivity cell and tissue fluorescence imaging[J]. J Biomed Opt, 2007,12(2).
[173] Cade NI, Fruhwirth G, Archibald SJ, Ng T and Richards D. A cellular screening assay using analysis of metal-modified fluorescence lifetime[J]. Biophys J, 2010,98: 2752-2757.
[174]Lakowicz JR. Radiative decay engineering 3. Surface plasmon-coupled directional emission[J]. Anal Biochem, 2004,324: 153-169.
[175]Gryczynski I, Malicka J, Gryczynski Z and Lakowicz JR. Radiative decay engineering 4. Experimental studies of surface plasmon-coupled directional emission[J]. Anal Biochem, 2004,324: 170-182.
[176]Gryzynski I, Malicka J, Gryczynski Z and Lakowicz JR. Surface plasmon-coupled emission: A new method for sensitive fluorescence detection[J]. Top Fluoresc Spectrosc, 2005,8: 381-403.
[177]Cao SH, Cai WP, Liu Q and Li YQ. Surface Plasmon-Coupled Emission: What Can Directional Fluorescence Bring to the Analytical Sciences?[J]. Ann Rev Anal Chem, 2012,5: 317-336.
[178]Gryczynski I, Malicka J, Gryczynski Z and Lakowicz JR. Surface Plasmon-Coupled Emission with Gold Films[J]. J Phys Chem B, 2004,108: 12568-12574.
[179]Aslan K and Geddes CD. Directional Surface Plasmon Coupled Luminescence for Analytical Sensing Applications: Which Metal, What Wavelength, What Observation Angle?[J]. Anal Chem, 2009,81: 6913-6922.
[180]Matveeva E, Gryczynski Z, Gryczynski I and Lakowicz JR. Immunoassays based on directional surface plasmon-coupled emission[J]. J Immunol Methods, 2004,286: 133-140.
[181]Matveeva EG, Gryczynski Z, Malicka J, Lukomska J, Makowiec S, Berndt KW, Lakowicz, JR and Gryczynski I. Directional surface plasmon-coupled emission: Application for an immunoassay in whole blood[J]. Anal Biochem, 2005,344: 161-167.
[182]Xie TT, Liu Q, Cai WP, Chen Z and Li YQ. Surface plasmon-coupled directional emission based on a conformational-switching signaling aptamer[J]. Chem Commun, 2009: 3190-3192.
[183] Borejdo J, Calander N, Gryczynski Z and Gryczynski I. Fluorescence correlation spectroscopy in surface plasmon coupled emission microscope[J]. Opt Express, 2006,14: 7878-7888.
[184] Gryczynski Z, Borejdo J, Calander N, Matveeva EG. and Gryczynski I. Minimization of detection volume by surface-plasmon-coupled emission[J]. Anal Biochem, 2006,356(1): 125-131.
[185] Balaa K, Devauges V, Goulam Y, Studer V, Lev'que-Fort S and Fort E. Live cell imaging with surface plasmon-mediated fluorescence microscopy[J]. Proc SPIE, 2009,7367: 736710/1-8.

[186] Mettikolla P, Calander N, Luchowski R, Gryczynski I, Gryczynski Z and Borejdo J. Kinetics of a single cross-bridge in familial hypertrophic cardiomyopathy heart muscle measured by reverse Kretschmann fluorescence[J]. J Biomed Opt, 2010,15(1): 017011.
[187] Zhang DG, Moh KJ and Yuan XC. Surface plasmon-coupled emission from shaped PMMA films doped with fluorescence molecules[J]. Opt Express, 2010,18: 12185-12190.
[188] Malicka J, Gryczynski I, Gryczynski Z and Lakowicz JR. Use of surface plasmon-coupled emission to measure DNA hybridization[J]. J Biomol Screen, 2004,9: 208-215.
[189] Cao SH, Zou ZX, Weng YH, Cai WP, Liu Q and Li YQ. Plasmon-mediated fluorescence with distance independence: From model to a biosensing application[J]. Biosens Bioelectron, 2014,58C: 258-265.
[190] Cao SH, Xie TT, Cai WP, Liu Q and Li YQ. Electric field assisted surface plasmon-coupled directional emission: An active strategy on enhancing sensitivity for DNA sensing and efficient discrimination of single base mutation[J]. J Am Chem Soc, 2011,133: 1787-1789.
[191] Malicka J, Gryczynski I, Gryczynski Z and Lakowicz JR. DNA Hybridization Using Surface Plasmon-Coupled Emission[J]. Anal Chem, 2003,75: 6629-6633.
[192] Aslan K, Previte MJR, Zhang Y and Geddes CD. Microwave-accelerated surface plasmon-coupled directional luminescence 2: a platform technology for ultra fast and sensitive target DNA detection in whole blood[J]. J Immunol Methods, 2008,331: 103-113.
[193] Matveeva EG, Gryczynski I, Barnett A, Calander N and Gryczynski Z. Red blood cells do not attenuate the SPCE fluorescence in surface assays[J]. Anal Bioanal Chem, 2007,388: 1127-1135.
[194] Lakowicz JR, Malicka J, Matveeva E, Gryczynski I and Gryczynski Z. Plasmonic technology: Novel approach to ultrasensitive immunoassays[J]. Clin Chem, 2005,51: 1914-1922.
[195] Matveeva E, Gryczynski Z, Gryczynski I, Malicka J and Lakowicz JR.. Myoglobin immunoassay utilizing directional surface plasmon-coupled emission[J]. Anal Chem, 2004,76: 6287-6292.
[196] Yuk JS, McDonagh C and MacCraith BD. Demonstration of a surface plasmon-coupled emission (SPCE)-based immunoassay in the absence of a spacer layer[J]. Anal Bioanal Chem, 2010,398: 1947-1954.
[197] Gryczynski I, Malicka J, Nowaczyk K, Gryczynski Z and Lakowicz JR. Effects of Sample Thickness on the Optical Properties of Surface Plasmon-Coupled Emission[J]. J Phys Chem B, 2004,108: 12073-12083.
[198] Gryczynski I, Malicka J, Nowaczyk K, Gryczynski Z and Lakowicz JR. Waveguide-modulated surface plasmon-coupled emission of Nile blue in poly(vinyl alcohol) thin films[J]. Thin Solid Films, 2006,510: 15-20.
[199] Calander N. Surface Plasmon-Coupled Emission and Fabry-Perot Resonance in the Sample Layer: A Theoretical Approach[J]. J Phys Chem B, 2005,109: 13957-13963.
[200] Bradshaw JT, Mendes SB and Saavedra SS. Planar integrated optical waveguide spectroscopy[J]. Anal Chem, 2005,77: 28A-36A.
[201] Hruby VJ, Alves I, Cowell S, Salamon Z and Tollin G. Use of plasmon waveguide resonance (PWR) spectroscopy for examining binding, signaling and lipid domain partitioning of membrane proteins[J]. Life Sci, 2010,86: 569-574.
[202] McKee KJ, Meyer MW and Smith EA. Plasmon Waveguide Resonance Raman Spectroscopy[J]. Analytical Chemistry, 2012,84: 9049-9055.
[203] Meyer MW, McKee KJ, Nguyen VHT and Smith EA. Scanning Angle Plasmon Waveguide Resonance Raman Spectroscopy for the Analysis of Thin Polystyrene Films[J]. J Phys Chem C, 2012,116: 24987-24992.
[204] Liu XQ, Liu Q, Xie KX, Cao SH, Cai WP and Li YQ. Surface plasmon-coupled emission of multicolor quantum dots[J]. Huaxue Xuebao, 2012,70: 2220-2225.
[205] Cao SH, Cai WP, Liu Q, Xie KX, Weng YH and Li YQ. Turning on fluorescence by plasmonic assembly with large tunable spacing: a new observation and its biosensing application[J]. Chem Commun, 2014,50: 518-520.
[206] Gryczynski I, Malicka J, Gryczynski Z, Nowaczyk K and Lakowicz JR. Ultraviolet Surface Plasmon-Coupled Emission Using Thin Aluminum Films[J]. Anal Chem, 2004,76: 4076-4081.
[207]Lakowicz JR, Malicka J, Gryczynski I and Gryczynski Z. Directional surface plasmon-coupled emission: a

new method for high sensitivity detection[J]. Biochem Biophys Res Commun, 2003,307: 435-439.
[208]Lakowicz JR. Radiative decay engineering 3. Surface plasmon-coupled directional emission[J]. Anal Biochem, 2004,324: 153-169.
[209]Cao SH, Cai WP, Liu Q and Li YQ. Surface Plasmon-Coupled Emission: What Can Directional Fluorescence Bring to the Analytical Sciences?[J]. Ann Rev Anal Chem, 2012,5: 317-336.
[210]Gryczynski I, Malicka J, Gryczynski Z and Lakowicz JR. Surface Plasmon-Coupled Emission with Gold Films[J]. J Phys Chem B, 2004,108: 12568-12574.
[211]Geddes CD, Gryczynski I, Malicka J, Gryczynski Z and Lakowicz JR. Directional surface plasmon coupled emission[J]. J Fluoresc, 2004,14: 119-123.
[212]Gryczynski I, Malicka J, Gryczynski Z and Lakowicz JR. Radiative decay engineering 4. Experimental studies of surface plasmon-coupled directional emission[J]. Anal Biochem, 2004,324: 170-182.
[213]Xie TT, Liu Q, Cai WP, Chen Z and Li YQ. Surface plasmon-coupled directional emission based on a conformational-switching signaling aptamer[J]. Chem Commun, 2009: 3190-3192.
[214] Aslan K and Geddes CD. Directional Surface Plasmon Coupled Luminescence for Analytical Sensing Applications: Which Metal, What Wavelength, What Observation Angle?[J]. Anal Chem, 2009,81: 6913-6922.
[215] Cao SH, Xie TT, Cai WP, Liu Q and Li YQ. Electric field assisted surface plasmon-coupled directional emission: An active strategy on enhancing sensitivity for DNA sensing and efficient discrimination of single base mutation[J]. J Am Chem Soc, 2011,133: 1787-1789.
[216] Liu XQ, Liu Q, Cao SH, Cai WP, Weng YH, Xie KX and Li YQ. Directional surface plasmon-coupled emission of CdTe quantum dots and its application in Hg(II) sensing[J]. Anal Methods, 2012,4: 3956-3960.
[217] Cai WP, Liu Q, Cao SH, Weng YH, Liu XQ and Li YQ. Prism-Based Surface Plasmon Coupled Emission Imaging[J]. ChemPhysChem, 2012,13: 3848-3851.
[218] Cao SH, Cai WP, Liu Q, Xie KX, Weng YH and Li YQ. Turning on fluorescence by plasmonic assembly with large tunable spacing: a new observation and its biosensing application[J]. Chem Commun, 2014,50: 518-520.
[219] Matveeva EG, Gryczynski Z, Malicka J, Lukomska J, Makowiec S, Berndt KW, Lakowicz JR and Gryczynski I. Directional surface plasmon-coupled emission: Application for an immunoassay in whole blood[J]. Anal Biochem, 2005,344: 161-167.
[220] Burghardt TP, Charlesworth JE, Halstead MF, Tarara JE and Ajtai K. In Situ Fluorescent Protein Imaging with Metal Film-Enhanced Total Internal Reflection Microscopy[J]. Biophy J, 2006,90(12): 4662-4671.
[221] Gryczynski Z, Borejdo J, Calander N, Matveeva EG and Gryczynski I. Minimization of detection volume by surface-plasmon-coupled emission[J]. Anal Biochem, 2006,356(1): 125-131.
[222] Zhang J, Fu Y, Mei Y, Jiang F and Lakowicz JR. Fluorescent metal nanoshell probe to detect single miRNA in lung cancer cell[J]. Anal Chem, 2010,82: 4464-4471.
[223] Yuan P, Lee YH, Gnanasammandhan MK, Guan Z, Zhang Y and Xu QH. Plasmon enhanced upconversion luminescence of NaYF4:Yb,Er@SiO2@Ag core – shell nanocomposites for cell imaging[J]. Nanoscale, 2012,4(16): 5132.
[224] Deng W and Goldys EM. Plasmonic Approach to Enhanced Fluorescence for Applications in Biotechnology and the Life Sciences[J]. Langmuir, 2012,28(225): 10152-10163.
[225] Ray A, Lee Y-EK, Kim G and Kopelman R. Two-Photon Fluorescence Imaging Super-Enhanced by Multishell Nanophotonic Particles, with Application to Subcellular pH[J]. Small, 2012,8(14): 2213-2221.
[226] Zhang J, Fu Y, Liang D, Zhao RY and Lakowicz JR. Enhanced Fluorescence Images for Labeled Cells on Silver Island Films[J]. Langmuir, 2008,24: 12452-12457.
[227] Muthu P, Calander N, Gryczynski I, Gryczynski Z, Talent JM, Shtoyko T, Akopova I and Borejdo J. Monolayers of silver nanoparticles decrease photobleaching: application to muscle myofibrils[J]. Biophys J, 2008,95: 3429-3438.
[228] Qiu T, Jiang J, Zhang W, Lang X, Yu X and Chu PK. High-Sensitivity and Stable Cellular Fluorescence Imaging by Patterned Silver Nanocap Arrays[J]. ACS Appl Mater Interfaces, 2010,2: 2465-2470.

[229] Gartia MR, Hsiao A, Sivaguru M, Chen Y and Liu GL. Nanoplasmon coupled intracellular optical resonance excitation for ultrasensitive 3D fluorescence cell imaging[J]. Proc SPIE, 2011,8099: 80990T/1-12.
[230] Moal EL, Fort E, L é v ê que-Fort S, Cordeli è res FP, Fontaine-Aupart MP and Ricolleau C. Enhanced Fluorescence Cell Imaging with Metal-Coated Slides[J]. Biophys J, 2007,92(6): 2150-2161.
[231] He RY, Chang GL, Wu HL, Lin CH, Chiu KC, Su YD and Chen SJ. Enhanced live cell membrane imaging using surface plasmon-enhanced total internal reflection fluorescence microscopy[J]. Opt Express, 2006,14: 9307-9316.
[232] He RY, Chiu KC, Su YD, Chang KL and Chen SJ. Study of cell adhesion and migration by using a plasmon-enhanced total internal reflection fluorescence microscope[J]. Proc SPIE, 2006,6088: 608802/1-8.
[233] He RY, Su YD, Cho KC, Lin CY, Chang NS, Chang CH and Chen SJ. Surface plasmon-enhanced two-photon fluorescence microscopy for live cell membrane imaging[J]. Opt Express, 2009,17: 5987-5997.
[234] He RY, Lin CY, Su YD, Chiu KC, Chang NS, Wu HL and Chen SJ. Imaging live cell membranes via surface plasmon-enhanced fluorescence and phase microscopy[J]. Opt Express, 2010,18: 3649-3659.
[235] Borejdo J, Calander N, Gryczynski Z, and Gryczynski I. Fluorescence correlation spectroscopy in surface plasmon coupled emission microscope[J]. Opt Express, 2006,14: 7878-7888.
[236] Borejdo J, Gryczynski Z, Calander N, Muthu P and Gryczynski I. Application of surface plasmon coupled emission to study of muscle[J]. Biophys J, 2006,91: 2626-2635.
[237] Calander N, Muthu P, Gryczynski Z, Gryczynski I and Borejdo J. Fluorescence correlation spectroscopy in a reverse Kretchmann surface plasmon assisted microscope[J]. Opt Express, 2008,16: 13381-13390.
[238] Lin CY, Chiu KC, Chang CY, Chang SH, Guo TF and Chen SJ. Surface plasmon-enhanced and quenched two-photon excited fluorescence[J]. Opt Express, 2010,18: 12807-12817.
[239] Mettikolla P, Calander N, Luchowski R, Gryczynski I, Gryczynski Z and Borejdo J. Kinetics of a single cross-bridge in familial hypertrophic cardiomyopathy heart muscle measured by reverse Kretschmann fluorescence[J]. J Biomed Opt, 2010,15(1): 017011/1-9.
[240] Chiu KC, Lin CY, Dong CY and Chen SJ. Optimizing silver film for surface plasmon-coupled emission induced two-photon excited fluorescence imaging[J]. Opt Express, 2011,19: 5386-5396.
[241] Balaa K, Devauges V, Goulam Y, Studer V, Lev'que-Fort S and Fort E. Live cell imaging with surface plasmon-mediated fluorescence microscopy[J]. Proc SPIE, 2009,7367: 736710/1-8.
[242]Gryczynski I, Malicka J, Nowaczyk K, Gryczynski Z and Lakowicz JR. Effects of Sample Thickness on the Optical Properties of Surface Plasmon-Coupled Emission[J]. J Phys Chem B, 2004,108: 12073-12083.
[243]Gryczynski I, Malicka J, Nowaczyk K, Gryczynski Z and Lakowicz JR. Waveguide-modulated surface plasmon-coupled emission of Nile blue in poly(vinyl alcohol) thin films[J]. Thin Solid Films, 2006,510: 15-20.
[244] Calander N. Surface Plasmon-Coupled Emission and Fabry-Perot Resonance in the Sample Layer: A Theoretical Approach[J]. J Phys Chem B, 2005,109: 13957-13963.
[245] Zhang LX, Cao XH, Cai WP and Li YQ. Observations of the Effect of Confined Space on Fluorescence and Diffusion Properties of Molecules in Single Conical Nanopore Channels[J]. J Fluoresc, 2011,21(5): 1865-1870.
[246] Gryczynski I, Malicka J, Gryczynski Z, Nowaczyk K and Lakowicz JR. Ultraviolet Surface Plasmon-Coupled Emission Using Thin Aluminum Films[J]. Anal Chem, 2004,76: 4076-4081.
[247] Aslan K, Zhang YX and Geddes CD. Surface Plasmon Coupled Fluorescence in the Visible to Near-Infrared Spectral Regions using Thin Nickel Films: Application to Whole Blood Assays[J]. Anal Chem, 2009,81(10): 3801-3808.
[248]Axelrod D. Total internal reflection flourescence microscopy[J]. Methods Cell Biol, 2008,89: 169-221.
[249]Reck-Peterson SL, Derr ND and Stuurman N. Imaging single molecules using total internal reflection fluorescence microscopy. 2010[C]. Cold Spring Harbor Laboratory Press.
[250]Mattheyses AL, Simon SM and Rappoport JZ. Imaging with total internal reflection fluorescence microscopy for the cell biologist[J]. J Cell Sci, 2010,123: 3621-3628.
[251]Millis BA. Evanescent-wave field imaging: an introduction to total internal reflection fluorescence

microscopy[J]. Methods Mol Biol, 2012,823: 295-309.
[252]Geddes CD, Gryczynski I, Malicka J, Gryczynski Z and Lakowicz JR. Metal-enhanced fluorescence: Potential applications in HTS[J]. Comb Chem High T Scr, 2003,6(2): 109-117.
[253]Lakowicz JR. Radiative decay engineering 3. Surface plasmon-coupled directional emission[J]. Anal Biochem, 2004,324: 153-169.
[254]Aslan K, Gryczynski I, Malicka J, Matveeva E, Lakowicz JR and Geddes CD. Metal-enhanced fluorescence: an emerging tool in biotechnology[J]. Curr Opin Biotech, 2005,16(1): 55-62.
[255]Lakowicz JR. Radiative decay engineering: Principles and biomedical applications of metal enhanced fluorescence. 2005[C]. American Chemical Society.
[256]Gryzynski I, Malicka J, Gryczynski Z and Lakowicz JR. Surface plasmon-coupled emission: A new method for sensitive fluorescence detection[J]. Top Fluoresc Spectrosc, 2005,8: 381-403.
[257] Cao SH, Cai WP, Liu Q and Li YQ. Surface Plasmon-Coupled Emission: What Can Directional Fluorescence Bring to the Analytical Sciences?[J]. Ann Rev Anal Chem, 2012,5: 317-336.
[258] He RY, Chiu KC, Su YD, Chang KL and Chen SJ. Study of cell adhesion and migration by using a plasmon-enhanced total internal reflection fluorescence microscope[J]. Proc SPIE, 2006,6088: 608802/1-8.
[259] He RY, Chang GL, Wu HL, Lin CH, Chiu KC, Su YD and Chen SJ. Enhanced live cell membrane imaging using surface plasmon-enhanced total internal reflection fluorescence microscopy[J]. Opt Express, 2006,14: 9307-9316.
[260] He RY, Su YD, Cho KC, Lin CY, Chang NS, Chang CH and Chen SJ. Surface plasmon-enhanced two-photon fluorescence microscopy for live cell membrane imaging[J]. Opt Express, 2009,17: 5987-5997.
[261] He RY, Lin CY, Su YD, Chiu KC, Chang NS, Wu HL and Chen SJ. Imaging live cell membranes via surface plasmon-enhanced fluorescence and phase microscopy[J]. Opt Express, 2010,18: 3649-3659.
[262] Su YD, Chiu KC, Chang NS, Wu HL and Chen SJ. Study of cell-biosubstrate contacts via surface plasmon polariton phase microscopy[J]. Opt Express, 2010,18: 20125-20135.
[263] Borejdo J, Calander N, Gryczynski Z and Gryczynski I. Fluorescence correlation spectroscopy in surface plasmon coupled emission microscope[J]. Opt Express, 2006,14: 7878-7888.
[264] Borejdo J, Gryczynski Z, Calander N, Muthu P and Gryczynski I. Application of surface plasmon coupled emission to study of muscle[J]. Biophys J, 2006,91: 2626-2635.
[265] Burghardt TP, Charlesworth JE, Halstead MF, Tarara JE and Ajtai K. In Situ Fluorescent Protein Imaging with Metal Film-Enhanced Total Internal Reflection Microscopy[J]. Biophy J, 2006,90(12): 4662-4671.
[266] Gryczynski Z, Borejdo J, Calander N, Matveeva EG and Gryczynski I. Minimization of detection volume by surface-plasmon-coupled emission[J]. Anal Biochem, 2006,356(1): 125-131.
[267] Gryczynski Z, Gryczynski I, Matveeva EG, Calander N, Grygorczyk R, Akopova I, Bharill S, Muthu P, Klidgar S and Borejdo J. New surface plasmons approach to single molecule detection (SMD) and fluorescence correlation spectroscopy (FCS)[J]. Proc SPIE-Int Soc Opt Eng, 2007,6444: 64440G/1-11.
[268] Calander N, Muthu P, Gryczynski Z, Gryczynski I and Borejdo J. Fluorescence correlation spectroscopy in a reverse Kretchmann surface plasmon assisted microscope[J]. Opt Express, 2008,16: 13381-13390.
[269] Balaa K, Devauges V, Goulam Y, Studer V, Lev'que-Fort S and Fort E. Live cell imaging with surface plasmon-mediated fluorescence microscopy[J]. Proc SPIE, 2009,7367: 736710/1-8.
[270] Lin CY, Chiu KC, Chang CY, Chang SH, Guo TF and Chen SJ. Surface plasmon-enhanced and quenched two-photon excited fluorescence[J]. Opt Express, 2010,18: 12807-12817.
[271] Mettikolla P, Calander N, Luchowski R, Gryczynski I, Gryczynski Z and Borejdo J. Kinetics of a single cross-bridge in familial hypertrophic cardiomyopathy heart muscle measured by reverse Kretschmann fluorescence[J]. J Biomed Opt, 2010,15(1): 017011/1-7.
[272] Chiu KC, Lin CY, Dong CY and Chen SJ. Optimizing silver film for surface plasmon-coupled emission induced two-photon excited fluorescence imaging[J]. Opt Express, 2011,19: 5386-5396.
[273] Tang WT, Chung E, Kim Y, So PTC and Sheppard CJR. Effects of using a metal layer in total internal reflection fluorescence microscopy[J]. Appl Phys A: Mater Sci Process, 2007,89: 333-335.

[274] Tang WT, Chung E, Kim Y-H, So PTC and Sheppard CJR. Investigation of the point spread function of surface plasmon-coupled emission microscopy[J]. Opt Express, 2007,15: 4634-4646.
[275] Tang WT, Chung E, Kim YH, So PTC and Sheppard CJR. Surface-plasmon-coupled emission microscopy with a spiral phase plate[J]. Opt Lett, 2010,35: 517-519.
[276] Zhang DG, Yuan XC and Bouhelier A. Direct image of surface-plasmon-coupled emission by leakage radiation microscopy[J]. Appl Opt, 2010,49: 875-879.
[277] Zhang DG, Moh KJ and Yuan XC. Surface plasmon-coupled emission from shaped PMMA films doped with fluorescence molecules[J]. Opt Express, 2010,18: 12185-12190.
[278] Zhang DG, Yuan XC, Yuan GH, Wang P and Ming H. Directional fluorescence emission characterized with leakage radiation microscopy[J]. J Opt, 2010,12: 035002/1-4.
[279] Zhang DG, Fu Q, Yi M, Wang XX, Chen YK, Wang P, Lu YH, Yao PJ and Ming H. Excitation of Broadband Surface Plasmons with Dye Molecules[J]. Plasmonics, 2012,7: 309-312.
[280] Zhang DG, Fu Q, Wang XX, Chen YK, Wang P and Ming H. Characterization of a dye doped planar polymer waveguide by leakage radiation microscopy[J]. J Opt, 2012,14: 015003/1-5.
[281] Chen YK, Zhang DG, Han L, Rui GH, Wang XX, Wang P and Ming H. Surface-plasmon-coupled emission microscopy with a polarization converter[J]. Opt Lett, 2013,38: 736-738.
[282] Aslan K and Geddes CD. Directional Surface Plasmon Coupled Luminescence for Analytical Sensing Applications: Which Metal, What Wavelength, What Observation Angle?[J]. Anal Chem, 2009,81: 6913-6922.
[283] Aslan K, Zhang YX and Geddes CD. Surface Plasmon Coupled Fluorescence in the Visible to Near-Infrared Spectral Regions using Thin Nickel Films: Application to Whole Blood Assays[J]. Anal Chem, 2009,81(10): 3801-3808.
[284] Gryczynski I, Malicka J, Gryczynski Z, Nowaczyk K, and Lakowicz JR. Ultraviolet Surface Plasmon-Coupled Emission Using Thin Aluminum Films[J]. Anal Chem, 2004,76: 4076-4081.