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Review article

Photon upconversion towards applications in energy conversion and bioimaging

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ABSTRACT

The field of plasmonics can play an important role in developing novel devices for application in energy and healthcare. In this review article, we consider the progress made in design and fabrication of upconverting nanoparticles and metal nanostructures for precisely manipulating light photons, with a wavelength of several hundred nanometers, at nanometer length scales, and describe how to tailor their interactions with molecules and surfaces so that two or more lower energy photons can be used to generate a single higher energy photon in a process called photon upconversion. This review begins by introducing the current state-of-the-art in upconverting nanoparticle synthesis and achievements in color tuning and upconversion enhancement. Through understanding and tailoring physical processes, color tuning and strong upconversion enhancement have been demonstrated by coupling with surface plasmon polariton waves, especially for low intensity or diffuse infrared radiation. Since more than 30% of incident sunlight is not utilized in most photovoltaic cells, this photon upconversion is one of the promising approaches to break the so-called Shockley-Queisser thermodynamic limit for a single junction solar cell. Furthermore, since the low energy photons typically cover the biological window of optical transparency, this approach can also be particularly beneficial for novel biosensing and bioimaging techniques. Taken together, the recent research boosts the applications of photon upconversion using designed metal nanostructures and nanoparticles for green energy, bioimaging, and therapy.

Abbreviations: AA, 6-aminohexanoic acid; AEP, 2-aminoethyl dihydrogen phosphate; AFM, atomic force microscope(y); ANOVA, analysis of variance; CAU, cooperative activation upconversion; CR, cross relaxation; CSU, cooperative sensitization upconversion; CTAB, cetyl trimethyl ammonium bromide; CW, continuous wave; DAPI, 4′,6-diamidino-2-phenylindole; DMSA, 3-dimercaptosuccinic acid; DNA, deoxyribonucleic acid; DSSCs, dye-sensitized solar cells; EDTA, ethylenediaminetetraacetic acid; EF, enhancement factor; EMU, energy migration-mediated upconversion; EQE, external quantum efficiency; ESA, excited state absorption; ETU, energy transfer upconversion; FDTD, finite-difference time-domain; FIB, focused ion beam; FITC, fluorescene isothiocynate; GNP, glycine-nitrate process; HAD, hexanedioic acid; HOMO, highest occupied molecular orbital; HRTEM, high-resolution transmission electron microscope(y); IR, infrared; MB, methylene blue; MEHPPV, poly(2-methoxy-5-(2′-ethylhexyloxy)-1,4-phenylene-vinylene); MPA, 3-mercaptopropionic acid; MRI, magnetic resonance imaging; NC, nanocrystal; NIR, near infrared; OA, oleic acid; ODE, 1-octadecene; OLA, oleylamine; OLA-PAA-PEG, octylamine-polyacrylic acid-polyethylene glycol; OOA, octadecyloleamine; OTA, octylamine; PA, photon avalanche; PAA, polyacrylic acid; PAH, poly(allylamine hydrochloride); PAMAM, poly(aminoamine); PDT, photodynamic therapy; PEG, polyethylene glycol; PEG-b-PCL, polyethylene glycol-block-polycaprolactone; PEG-b-PLA, polyethylene glycol-block-polylactic acid; PEI, polyethylenimine; PL, photoluminescence; PLL, poly(L-lysine); PMAO, poly(maleic anhydride-alt-1-octadecene); PSS, polystyrene sulfonate; PVP, polyvinylpyrrolidone; RIE, reactive ion etching; SEM, scanning electron microscope(y); SPP, surface plasmon polariton; TEM, transmission electron microscope(y); TEOS, tetraethoxysilane/tetraethyl orthosilicate; TGA, thioglycolic acid; TOP, trioctylphosphine; TOPO, trioctylphosphine oxide; TUNEL, terminal deoxynucleotidyl transferase dUTP Nick-end labeling; UC, upconversion; UCNPs, upconversion nanoparticles; UPL, upconversion photoluminescence; XRD, X-ray powder diffraction.

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