The beautiful phenomena of nonlinear optics are explored now more than 50 years. Frequency mixing and harmonics generation, phase conjugation, multi-photon absorption processes, parametric oscillation, electro-optic modulation etc. are well-known and explained within classical electrodynamics. In the last decade, concepts of nonlinear optics were taken up for new, complex artificial materials and nanostructure-based devices. New chances to exploit light-matter interaction, besides traditional lasers, appear in such exciting systems as qubits, photonic crystals and plasmonic nanocavities, superconducting quantum circuits etc. bridging the gap between (semi)classical nonlinear optics and quantum optics.

In this contribution we give an overview about present concepts to exploit principles of nonlinear optics in telecommunication and sub-wavelength optics. We will then focus on two examples of using nonlinear optics for new devices. In case of (i) of InGaAs-quantum dot based semiconductor optical amplifiers (QD-SOAs) the ultrafast gain dynamics, cross-gain and cross-phase modulation will be presented and its advantage for ultrafast nonlinear signal processing discussed. In case of (ii) a potential use of surface-plasmon (SP) nonlinearities for subwavelength OPOs, parametric downconversion and source of entangled SP pairs at ultra-compact length scales will be presented.

The experimental methods we apply are femtosecond heterodyne two-color pump-probe experiments which allow the direct measurement of the nonlinear response in amplitude and phase. Two independently tunable, synchronized laser beams give access to simultaneous studies of cross-gain modulation (XGM) and cross-phase modulation (XPM) within an inhomogeneously broadened QD-ensemble at wavelength differences between pump and probe pulses ranging from about 10 nm to 300 nm. We determine the dynamics of coupled reservoir and QD states and discuss their role in wavelength conversion processes in QD SOAs. Self-assembled InGaAs quantum dots (QDs) show gain recovery in the range of a few picoseconds enabling pattern-effect-free signal amplification up to high bit-rates of 80Gb/s @ 1.3μm. QD Electrical pumping influences the population filling of the carrier reservoir as well its depletion into the QD states and thus couples the (2D) reservoir dynamics with the (1D) intra-dot carrier dynamics.

The plasmonic systems were analysed in high-resolution k-space spectroscopy in Kretschmann geometry to examine the emitted SHG in a way that provides precise information on SP nonlinear phase-matching. We propose that all permutations of surface plasmon (p) and photon (f) are allowed in the second-order nonlinear process of SHG, which can generate either p or f; and that each process can be identified by its condition for momentum conservation (e.g. ff,f, pp,f, pf,f, ff,f, pp,p). Because each type of nonlinear interaction conserves momentum, we can distinguish them by their unique signature in k-space. Our results on thin silver films show that the role of the surface-plasmon is not merely to provide a local field enhancement for driving SHG at the metal surface, but it is the fundamental surface plasmons themselves that are annihilated and convert into the second-harmonic photon. Based on that result, concepts of plasmon quantum-optics, e.g. a plasmon-based entangled photon sources and a source of squeezed light are ultimate visions for future devices.