Текст 1

Due to the weakness of the nonlinear response of conventional materials, only selected, nonlinear materials exhibit considerable nonlinear optical eﬀects at reasonable light intensities, and typically a long propagation length in a material is needed to achieve signiﬁcant nonlinear eﬀects.[1,2]

In order to increase the eﬃciency of light-matter interactions in a linear domain, plasmonic modes in conductors and their nanostructures, including metal-dielectric metamaterials, have recently been widely used.[3–9]

Nonlinear plasmonics has been developed utilising the above-described properties of plasmonic ﬁeld, while also taking advantage of the nanoscale range of plasmonic modes enabling to achieve nonlinear response on subwavelength scales and, thus, being naturally compatible with integrated optics. There are two typical approaches: (i) to use the ﬁeld enhancement provided by surface plasmons to induce a nonlinear response in nonlinear dielectric near the metal interface in hybrid metal-dielectric systems or (ii) to harvest the nonlinearity of plasmonic materials themselves. In the latter case, a nonlinear response originates from the dynamics of non-equilibrium free-electrons in the medium under the inﬂuence of strong electromagnetic ﬁeld of the illumination. Indeed, the metal nonlinear response is one of the strongest per unit interaction length and fastest, with the emtosecond-scale response time determined by relaxation of the excited electrons to the equilibrium state, governed primarily by electron-electron and electron-phonon scattering. Both approaches were exploited for enhancement of coherent nonlinear interactions, such as harmonics generation and wave mixing, as well as Kerr-type nonlinearities for controlling light with light.

The hydrodynamic treatment was ﬁrst used by Ritchie in his seminal work,[19] where he predicted the existence of surface plasmons.

Текст 2

The study of the nonlinear optical response of matter is important for various disciplines such as biology, information sciences and physics, especially when dealing with nanometer length scales [1–4]. It is therefore important to have efficient sources of nonlinear optical signals at such length scales. Second harmonic generation (SHG) is one such important nonlinear optical effect, which has the added advantage of being sensitive to symmetry. Under the dipole approximation, SHG is forbidden for centrosymmetric media; however since inversion symmetry is broken at an interface, one can use nonlinear SHG microscopy to study even centrosymmetric structures on surfaces [5]. It is well-known that plasmonic dipole antennae (DA) exhibit so-called hot spots in their gap, where the incident intensity can be enhanced by several orders of magnitude [6]. In recent years, experimental work [7, 8] and simulations [9] dealing with the SHG in dipole antennae have been reported. As the intensity of the second-harmonic signal is proportional to the square of the fundamental field intensity, this second-order nonlinear process can strongly benefit from the high enhancement of the incident field in these structures. Yet, all the previous studies in plasmonics rely on the enhancement of the fundamental field only and do not consider any resonance at the doubled frequency. This approach based on two resonances has been successfully demonstrated in traditional optics, for example in resonant Fabry-Perot microcavities [10–12]. In this work, we propose and experimentally demonstrate a novel plasmonic antenna geometry with two gaps that are coupled to each other, both of which exhibit a resonance at the fundamental and doubled frequency, and thus enhance simultan

Текст 3

Nonlinear optics has triggered the evolution of modern

optics, yielding discoveries of important phenomena, deep

understandings of fundamental optical effects and, moreover,

serving as a source for a large variety of applications. Nonlinear

optical interactions are relatively weak but can be significantly

enhanced using various approaches. Generally, nonlinear

optical phenomena are proportional to higher orders of the

driving field, motivating the quest for local electromagnetic

field enhancement for which various nanostructures have

been proven to be beneficial. In particular, noble metals with

negative permittivity at optical and infrared wavelengths can

support the so-called surface plasmon modes with the deep-

subwavelength localization of the electromagnetic energy,

overcoming the conventional diffraction limit and leading to

the field enhancement effects.1 Plasmonic nanostructures are

perfect candidates for the realization of various concepts for the

enhancement of nonlinear effects. Surface-enhanced Raman

scattering (SERS) is one of the most famous examples of

plasmonic-enhanced processes: a rough noble metal surface

was shown to enhance the magnitude of the scattering by 14

orders of magnitude compared to the conventional process. 2

The advantage of doubly resonant plasmonic structures was

demonstrated for SERS where a pair of particles provides

the resonant enhancement for both the pump and Stokes

frequencies.3 The grooves etched in a metal surface and

organized into a grating geometry have been shown to enhance

the four-wave mixing (FWM) efficiency by two orders of

magnitude. 4 Four orders of magnitude improvement of FWM

was demonstrated with a plasmonic dimer configuration. 5

Optical nonlinearities assisted by plasmonic nanostructures

have recently been proposed for various applications in active

photonic components,6 sensing, 7 and signal processing. 8

Second-harmonic generation (SHG) is the most basic

nonlinear process in which two photons combine to create

a photon at double frequency. There are many literature

reports on the study of various SHG-based plasmonic devices.

For instance, core-shell nanocavities have been shown to

enhance the nonlinear SHG conversion in a nonlinear core

by two to three orders of magnitude. 9 Nanorings of GaAs

incorporated in a gold film have been shown to enhance

the SHG in the wavelength range corresponding to the

enhanced transmission of the film. 10 Dark plasmonic modes

(weakly coupled to far-field radiation) may be excited via

second-harmonic generation.11 SHG from small metal clusters

and rough surfaces was investigated in Ref. 12, although

the multiple resonant structure was ignored. In the previous

studies, nonlinear interactions were considered to originate

from either nonlinear dielectric materials and then be enhanced

by the metal structures or bulk and surface metal nonlinearities,

which are not always straightforward to distinguish. 13

Furthermore, nanoscale nonlinear processes are essentially

different from conventional nonlinear phenomena. 14 One of

the fundamental requirements of the “propagating-wave” non-

linear optics is the fulfillment of phase-matching conditions:

fundamental and second-harmonic waves have to propagate

in phase in order to create constructive interferences and,

thus, considerably increase the efficiency of the conversion

process.15 The possibility of fabricating small photonic cavi-

ties initiated the studies of cavity nonlinear optics where the

classical phase-matching conditions are replaced by a spatial

overlap of localized modes at fundamental and second har-

monic frequencies in order to obtain an enhanced conversion

efficiency. 16 Hence, investigations of nontrivial conditions

for optimized nonlinear interactions in subwavelength plas-

monic objects are of potential fundamental and applicative

interest.