Harmonic generation in metals and semiconductors-A review

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Abstract

Harmonic generation in different materials has been a topic of interest for many researchers from many decades. Different materials have been explored under different conditions. Laser interacts with particles of material and accelerates them. Velocity of particles beats with the fields of laser and show different phenomena; one of them is generation of higher harmonics. This paper contains review on harmonic generation in metals and semiconductors.

Key words: Non-linear interactions, surface plasmons, charge concentration.

A Review Report

The interaction of em fields of laser with matter creates plasma. The charge carriers of matter get accelerated producing non linear effects. Type of plasma formed depends on nature of material and parameters of laser used. In metals free electrons form plasma upon interaction with em fields. Electrons beat with electric and magnetic fields and leads to non linear current density producing non linear effects like generation of harmonic waves with frequency higher than the frequency of incident light. In metals interaction of photons and electrons also gets influenced by electron-electron and electron-ion interactions. In metals harmonic generation from bulk arises due to polarization of magnetic dipole source or two types of surface polarizations which include parallel and perpendicular modes. Out of these, the contributions of bulk and parallel surface depend only on bulk properties and they are not surface sensitive. Hence main contribution to non linear phenomena in metals is due to surface effects. However presence of adsorbents over metal surface may reduce contribution of normal surface polarizations then bulk and parallel surface contributions dominate.[1] Timbrell *et. al.* showed that for metals surface contribution to non linear power generation is much more than bulk contributions.[2] The non linear behavior arises because of interaction of photons with atoms of metallic surface. Metal clusters which are made of several hundreds of atoms supports plasmon excitations.[3] In metals interaction of photons with surface plasmons lead to polaritons and corresponding waves are called surface plasmon polaritons (SPP). In past few years SPP based structures have gained great importance due to its properties and applications in optics, Surface enhanced Raman spectroscopy (SERS), data storage etc. Electrons or photons can excite SPPs but in case of photons presence of other agents like prisms or gratings or defects on metal surface is needed. Such interactions lead to production of harmonic waves. Surface plasmon resonance based circuit has overcome the limitations related to size of circuits to be used in data processing nano devices with high performance.[4] By using nano structures specifically made out of metals like Ag, Ni, Au etc. external em fields can be localized on length scales of just a few nanometers, resulting in greatly enhanced field amplitudes that can exceed those of the external field by orders of magnitude in the vicinity of nanostructures. Metals like Ag, Au have been studied and give good response but work on metals like Co, Ti, Ni, metal oxides has also been done in past few years.[5] For metal vacuum interface, surface plasma wave of large amplitude heats up the electrons and gets absorbed, this increase in temperature causes thermionic emission of electrons. To attain large amplitude required for surface plasma waves can be attained by depositing a metal film on face of prism in attenuated total reflection configuration.[6] Harmonics generated from magnetic resonance in Al-GaAs on aluminium oxide nanoantennas can be made resonant by varying height and radius of nanoantennas and irregularities in metal surfaces behave equivalently to nanostructures.[7] Nano particles made of high refractive index dielectric materials have been proposed as an alternative to metals, driven by their low losses and presence of magnetic response inspite of being non magnetic materials. They suffer large losses and absence of magnetic response at optical frequencies.[8] Nature of waves generated depends on angle of incidence also as if laser beams of different frequencies are incident on metal surface at angles θ and $-\theta$ then surface plasma wave with frequency equals to their difference is formed and frequency of surface wave depends upon incident frequencies and angels.[9] Presence of density ripple of suitable wave number on metal surface produces non linear current which give rise to plasma wave of different frequencies.[10]

In semiconductors charge carriers are electrons or holes depending type of doping. Number density is one of the important characteristics. Interaction of laser with semiconductors forms different types of plasma like under dense plasma, over dense plasma etc. Kant *et. al.* have studied such plasmas under different conditions and concluded presence of density ripple enhances wave amplitude to remarkable extent. Their study also includes impact of different laser profiles like Gaussian profile, Hermite Gaussian and Hermite-cosh Gaussian.[11,12] The electric and magnetic fields of laser drifts electrons creating non linear current density and leading to production of different harmonics. The amplitude and type of harmonic is decided by frequency of incident laser, charge carrier concentration. Other agents like presence of density ripple, wiggler field, chirp pulse also enhances efficiency of production and amplitude of wave generated. Thakur *et al.* have observed the effect of chirp, wiggler field with density ripple and has found good enhancement in harmonic amplitude.[13–16]For third harmonic generation in n-InSb and Ag enhancement in the electric field in case of n-InSb by order of 2 has been observed than for Ag due to high non linear density in semiconductors than metals.[17] Combination of metals with dielectrics also lead to formation of higher harmonics at the interface, surface plasma waves of metals help in this phenomena.[8] Charge density is one of the important deciding factors for the order of harmonic generation, highly doped semiconductors respond satisfactorily for the same.

Both metals and semiconductor show high harmonic generation due to interaction of em fields with charge particles particularly electrons. Both show non linear behavior upon interaction which leads to non linear current density producing harmonic waves as well as other non linear phenomena. Metals which are generally good conductors like Ag, Au, and Al or with good magnetic properties like Co, Ni etc. show harmonic generation upto good extent. In case of semiconductors charge concentration depends on doping which facilitates this process. Recent work includes generation of waves in layered pattern like metal-dielectric interface, metal-metal oxide etc. Advancements in this field will lead to improvement in imaging techniques.

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