Phase Locked Harmonics Etalon Localization in Opaque Materials

C. Cojocaru[1], V. Roppo[1,3], G. D'Aguanno[3], F. Raineri[2], J. Trull[1], R. Raj[2], R. Vilaseca[1], M. Scalora[3]

[1.] Departament de Física i Enginyeria Nuclear, Universitat Politècnica de Catalunya, ETSEIAT
Colom 11, E-08222 Terrassa, Spain
phone: +34 937398076; e-mail: crina.maria.cojocaru@upc.edu
[2.] Laboratoire de Photonique et de Nanostructures (CNRS UPR 20)
Route de Nozay 91460 Marcoussis, France
[3.] C. M. Bowden Research Facility, RDECOM, US Army Aviation and Missile Command
Reds-tone Arsenal, AL 35803, USA

ABSTRACT

In this work we investigate the behaviour of the phase locked second and third harmonic generated and propagating within a cavity of GaAs designed to be resonant for the fundamental field. We show that not only that the phase locked harmonics components are transmitted trough an opaque material (inhibition of the absorption), but also that the conversion efficiency of this harmonics is substantially increased.

Keywords: nonlinear optics, harmonic generation

1. INTRODUCTION

During the last decades, a phase locking phenomenon has been observed for second harmonic (SH) generation but, only recently, it was recognized as such in systematic studies [1]. The general solution of the SHG from a linear/nonlinear boundary layer is composed of one reflected and two forward propagating components. One of these forward components displays a k-vector that is a solution of the homogeneous wave equation (i.e. the expected SH wave vector). The second component displays a different k-vector, solution of the inhomogeneous wave equation – *the phase locked (PL) component* – equal to twice the pump wave vector. The key result is that the PL SH component effectively "reads" the value of the refractive index of the fundamental frequency (FF). Ref. [2] demonstrates that the PL SH signal is transmitted through a thick sample, even though the SH was tuned above the absorption band edge. This means that the imaginary part of $n(\omega)$, i.e. the absorption coefficient, is also impressed on the PL SH component. A sufficient condition for the effect to occur is that the pump be tuned to a region of optical transparency.

Here we investigate the behaviour of PL SH generated signal when it propagates in a cavity made of an opaque material for the SH frequency and designed to be resonant only for the fundamental field. We show that not only that the PL SH component is transmitted trough the opaque material (inhibition of the absorption), but also that the conversion efficiency of this SH component may be substantially increased when propagation occurs in a cavity designed to be resonant for the fundamental beam.

2. EXPERIMENTAL

As a first step we study the localization characteristics of a fundamental pump pulse, along with the second harmonic generated signal in a GaAs etalon with an optical thickness equal to the fundamental wavelength in the material. Fig. 1b shows the dispersion relation for the GaAs; the fundamental and the firsts two harmonics are marked.

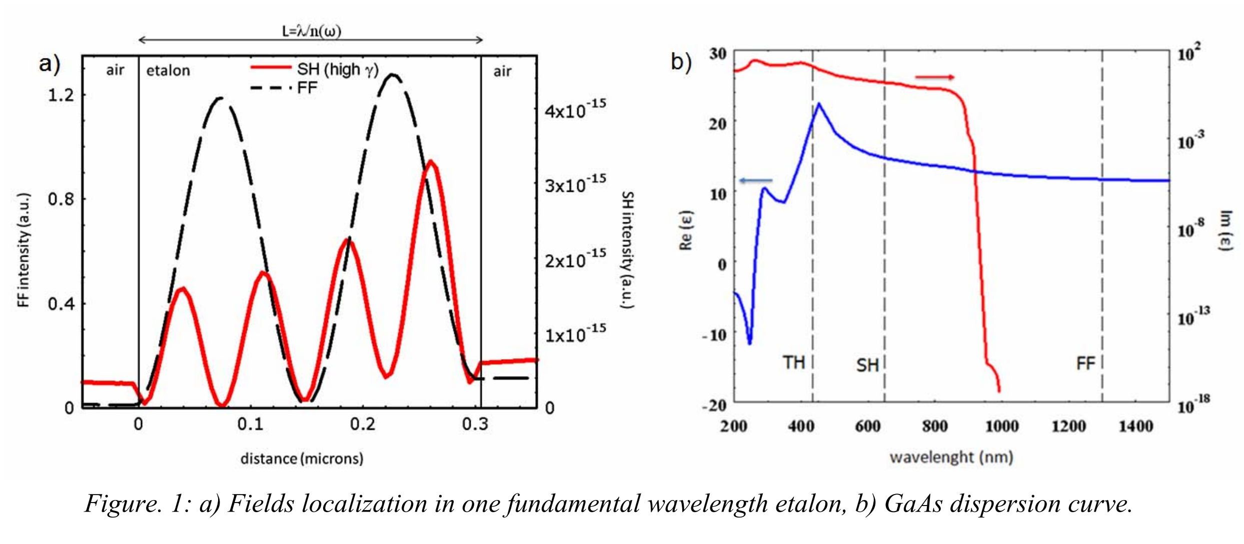

Figure. 1: a) Fields localization in one fundamental wavelength etalon, b) GaAs dispersion curve.

We chose the fundamental wavelength in the range of transparency while the SH falls in the opaque wavelength range. Conventional wisdom dictates that this structure should be resonant for the FF, but not for the SH signal. While this is true for the homogeneous component, the PL mechanism causes part of the SH signal to also resonate inside the cavity. Fig. 1a shows what happens to SH field localization. The presence of absorption at the SH frequency causes the amount of PL SH signal to increase compared to the amount of homogeneous signal, so that the SH signal localizes as if it were *reading the real part of index of refraction at the FF*. As a direct consequence of this anomalous field localization, an effective SH energy conversion is present despite the high nominal absorption and an apparently *"wrong"* cavity length for the SH field. This PL effect is also proved numerically and experimentally for the third harmonic generation and the theory is still valid for any harmonics.

Here we want to answer to the following question: what happens with the PL components of the harmonics within a cavity where only the fundamental field resonates? The answer is all the harmonics resonate as well. This is due the double action of the fundamental localization and *of the anomalous harmonics localization* (Fig. 1a). To experimentally prove this phenomenon we have design and optimized a cavity consisting of 645 nm of GaAs with a gold mirror on the back. The gold mirror improves the overall *Q* of the cavity, in order to increase the SH efficiency. For a pump tuned to 1300 nm the SH conversion efficiency as a function of the cavity length is shown in Fig. 2. The SH peaks are placed in correspondence of the resonance length of the cavity for the fundamental. A conversion efficiency of 10^{-8} is obtained for an input intensity of 100 W/cm^2 and $\chi^{(2)}$ = 10pm/V. As shown in Fig. 2, notwithstanding the low efficiency of the PL SH, the resonance effect produces one order of magnitude enhancement of the SH efficiency with respect to the GaAs etalon without mirrors. Similar effect is also observed for the third harmonic (TH).

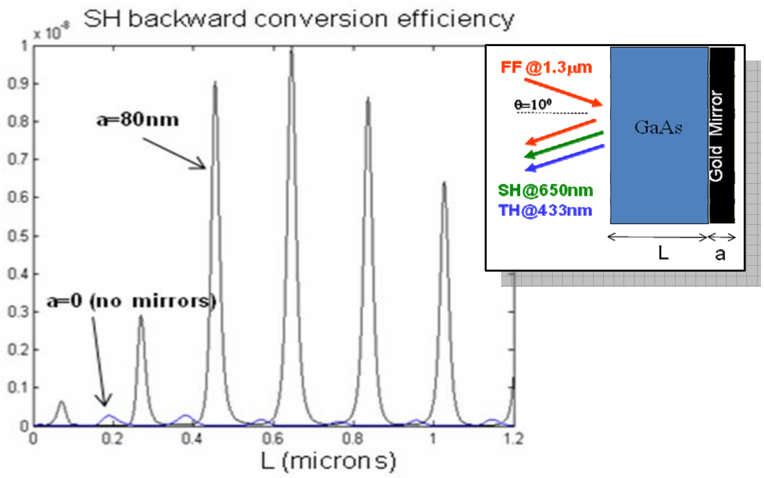

Figure 2. SH conversion efficiency as a function of the GaAs thickness; inset: schematic representation of the sample.

The experiment that we have developed consists in scanning the sample's resonance around 1300 nm with a tunable laser and to retrieve the SH an TH signal. For the study of the nonlinear behaviour, the fundamental field is incident on to the sample with a 10° angle so that $\chi^{(2)}$ is not null. The measured SH and TH conversion efficiencies are shown to be maxima when the fundamental field is exactly in resonance with the cavity. These preliminary experimental results are in perfect agreement with the prediction of our numerical simulations clearly showing the harmonics localization and enhancement at the fundamental frequency resonance in a material that is, in principle, not transparent for the harmonics frequencies.

3. CONCLUSIONS

The consequences of this work can be far reaching, because they open the door to the examination of new optical phenomena at, or near resonance. The results reported here are valid for all kind of semiconductors. The right choice of material (based on the transparent window at the fundamental) and the design of a high-Q cavity could lead to a high conversion efficiency and thus new, low cost and easy to build, UV sources. Other applications could also be the achievement of sub wavelength resolution and a new management of etalon effects.

REFERENCES

[1] V.Roppo *et al.,Phys. Rew. A* **76**, 033829, (2007).
[2] M. Centini *et al.,Phys. Rew. Lett.* **101**, 113905, (2008).