Abstract

Nature is nonlinear. The linear description of physical phenomena is useful for explain observations with the simplest mathematical models, but they are only accurate for a limited range of input values. In the case of intense acoustics waves, linear models obviate a wide range of physical phenomena that are necessary for accurately describe such high-amplitude waves, indispensable for explain other exotic acoustic waves and mandatory for developing new applied techniques based on nonlinear processes. In this Thesis we study the interactions between nonlinearity and other basic wave phenomena such as non-classical attenuation, anisotropic dispersion and periodicity, and diffraction in specific configurations.

We start presenting intense strain waves in a chain of cations coupled by realistic interatomic potentials. Here, the nonlinear ionic interactions and the dispersion of the lattice leads to the formation of supersonic kinks. These intrinsically-nonlinear localized dislocations can travel for long distances without changing its properties and can explain the formation of dark traces in mica crystals. Then, we increase the scale of the lattice in order to analyze nonlinear wave processes in a system composed of layers with alternating acoustic properties. The rich nonlinear dynamics of this system is characterized by its strong dispersion. Here, harmonic generation processes and the relation with its band structure are presented, showing that the nonlinear processes can be enhanced, strongly minimized or simply modified by tuning the layer parameters. In this way, we show how the dynamics of intense monochromatic waves and acoustic solitons can be controlled by artificial layered materials.

In a second part, we include diffraction and analyze four types of singular beams. First, we study beams in a two dimensional arrangement of cylindrical scatters (sonic crystal). In this system, the inclusion of anisotropic dispersion is tuned for obtain simultaneous self-collimation for fundamental and second harmonic beams. The conditions for optimal second harmonic generation are presented. Thus, both beams propagate in non-diffractive regime and do not spread during propagation. Secondly, we present limited diffraction beam generation using equispaced axisymmetric diffraction gratings. The obtained beams are truncated version of zero-th order Bessel beams. Third, the grating spacing can be modified to achieve focusing, obtaining acoustic Fresnel Zone Plates. Here, generated beams presents high focal gain, around 30 dB, with a focal width which is between the diffraction limit and the sub-wavelength regime, but with its characteristic high amplitude side lobes. However, due to the strong focusing, the nonlinear effects generates second harmonic mainly locally. Thus, second harmonic focus maintains the good spatial resolution, but having strongly reduced side lobes. Finally, we observe that waves diffracted by spiral-shaped gratings generate high-order Bessel beams, conforming nonlinear acoustic vortex. The conditions to obtain arbitrary-order Bessel beams by these passive elements are presented.

In the last part or the Thesis, the interplay of nonlinearity and attenuation in biological media is studied in the context of medical ultrasound. First, a finite differences numerical method is developed. The method solves the constitutive relations for nonlinear acoustics and the frequency power law attenuation of biological media is modeled as a sum of relaxation processes. A new technique for reducing numerical dispersion based on artificial relaxation is included. The method is validated with analytical solutions and experimental data. Second, this method is used to study the role in the nonlinear propagation of the specific frequency power law attenuation observed in biological media. The harmonic balance is studied a a function of the power law. In addition we show the role of weak dispersion and its impact on the efficiency of the harmonic generation in soft-tissues. Finally, the study concerns to the nonlinear behavior of acoustic radiation forces in

frequency power law attenuation media. We present how the interplay between nonlinearity and the specific frequency power law of biological media can modify the value for acoustic radiation forces. Furthermore, we show the relevance of using these nonlinear approximation to accurately describe acoustic radiation forces in soft tissues, and its connections with the energy deposition on the media. The relation of the nonlinear acoustic radiation force with thermal effects are also discussed.

The broad range of nonlinear processes analyzed in this Thesis contributes to understanding the behavior of intense acoustic waves traveling trough complex media, while its implications for enhancing existent applied acoustics techniques are presented.