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Role of Plasma Physics in service to society

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Abstract

Plasma is defined as an assemblage of charged particles called electrons and ions that react collectively to forces exerted by electric and magnetic fields. Plasma consists of a collection of free-moving electrons and ions - atoms that have lost electrons. Energy is needed to strip electrons from atoms to make plasma. The energy can be of various origins: thermal, electrical, or light (ultraviolet light or intense visible light from a laser). With insufficient sustaining power, plasmas recombine into neutral gas. Plasma can be accelerated and steered by electric and magnetic fields which allows it to be controlled and applied. Plasma research is yielding a greater understanding of the universe. It also provides many practical uses: new manufacturing techniques, consumer products, and the prospect of abundant energy. Because of their self-consistent motions, plasma are rampant with instabilities, chaosity, and nonlinearities. These also produce electric and magnetic fields but also electromagnetic radiation. For example, all beams of electrons produce microwaves. Plasma science has, in turn, spawned new avenues of basic science. Most notably, plasma physicists were among the first to open up and develop the new and profound science of chaos and nonlinear dynamics.

Key-Words: Plasma, Society, Fields.

Introduction

Plasma is created when matter is heated to over 10,000 degrees. The Sun and stars are in a plasma state maintained by thermonuclear fusion reactions. For years, laboratories around the world have been working to harness this immense power. Now innovators like Dr. Akira Hirose, the University of Saskatchewan's Canada Research Chair in Plasma Science, are finding exciting new applications for plasma research.

"Plasma is ideally suited for material processing and synthesis,"Dr. Hirose says. "Fabrication of sub-micron computer chips, for example, would not have been realized without plasma technology. Micro-fabrication requires precision etching, deposition and doping. This can be done most effectively in plasma discharges."

Dr. Hirose is also Director of the Plasma Physics Laboratory at the U of S. "We recently synthesized diamond grains and carbon nanotubes in the Laboratory. Diamond is an ideal material for micro-electronics because of its high thermal conductivity, and materials based on carbon nanostructures are stronger than steel, though much lighter, and have unique electronic properties such as electron emission when heated."

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Potential applications of the technology include the use of carbon nanotubes in computer displays and the manufacture of diamonds for industrial strength cutting tools. Diamond grains recently synthesized in the Laboratory by Dr. Xiao and Dr. Hirose were analyzed at a synchrotron facility at the University of California at Berkeley, which confirmed their crystal structure. Dr. Hirose is looking forward to the completion of the Canadian Light Source at the University of Saskatchewan.

Two more advanced plasma reactors are currently being built in the Plasma Physics Laboratory to synthesize diamond films and carbon nanostructures, and to improve the economic competitiveness of the processing technologies.

"The carbon nanotubes are still expensive to fabricate," Dr. Hirose says. "The first step is to develop a means of economic mass production. We are working in collaboration with other research laboratories around the world, particularly in Japan."

Plasma processing also has important applications. It can be used to apply a corrosion and wear-resistant coating on various surfaces, both metallic and non-metallic. It is also becoming increasingly important for cleaning, activating and sterilizing the surfaces of a variety of materials, such as those used in waste management.

While recognized for his leadership in plasma-based material science, Dr. Hirose first came to international prominence through his work in nuclear fusion. In the 1980s, he constructed Canada's first 'tokamak' (doughnut-shaped) fusion device. In 1992, his theory for anomalous electron thermal conductivity in tokamak reactors and his prediction of two new instabilities in tokamak magnetic geometry were heralded as major steps forward in understanding the problems in achieving fusion.

With the funding provided by the Chairs Program, Dr. Hirose hopes to accelerate development of innovative new technologies in plasma-based material science. It is cutting edge research that will lead to major improvements in the strength, quality and durability of materials used in a broad range of medical and commercial applications.

Some research examples of plasma physics in the field of non linear wave instabilities in piezoelectric material taking strain dependent dielectric constant

1. **Modulational instability of a laser beam in a piezoelectric material with strain dependent dielectric constant**

Analysis of the modulational instability of a laser beam has been investigated analytically in a plasma of piezoelectric material with strain dependent dielectric constant. The threshold field and the growth rate of the unstable mode have been deduced and it is concluded that a large growth rate can be achieved in materials with high dielectric constant, which is otherwise not achievable with piezoelectric interactions

2. Parametric Instabilities of Laser Beams in Material with Strain-Dependent Dielectric Constant

The parametric excitation of acoustic waves in material with strain-dependent dielectric constant is analysed. The analysis is based on the hydrodynamic model of plasma in the collision dominated regime. Using the coupled mode theory the parametric instability in the medium is investigated. The conditions for the excitation of the unstable acoustic mode and the necessary threshold value of the pump electric field are obtained. It is found that anomalously large values of growth can be obtained for materials with large values of the dielectric constant, which otherwise cannot be achieved with piezoelectric interaction. Numerical estimations are made for a $BaTiO_3$ crystal irradiated with a pulsed 10.6 μm CO, laser.

3. Brillouin Instability in Longitudinally Magnetized Crystals with High Dielectric Constant

An analytical investigation is made of the stimulated Brillouin Scattering of a plane polarized intense electromagnetic wave propagating parallel to the applied magnetic field in a n-type semiconducting plasma with high dielectric constant. The general dispersion relation is obtained and solved for both, the cases of scattered electromagnetic waves (i.e. in the case of left hand and right hand circularly polarized waves) to study the threshold condition and the growth rate of the unstable Brillouin mode at a pump amplitude well above the threshold. It is found that the threshold pump amplitude is independent of applied magnetic field and is the same for both types of polarization. The growth rate of the unstable Brillouin mode has linear dependence on the magnetic field. Numerical estimations are made for n-$BaTiO_3$irradiated with a pulsed 10.6 μm CO_2 laser to obtain the necessary electric field.

4. Nonlinear behaviour of piezoelectric lead zinc niobate–lead titanate single crystals under ac electric fields and dc bias4.

The nonlinear behaviours of the dielectric and piezoelectric responses of ^001& oriented Pb(Zn1/3Nb2/3)O3-*x*PbTiO3 ~PZN-PT! single crystals for *x*54.5% and 8% have been investigated as a function of ac electric fields and dc bias fields. At relatively low applied fields, the polarization and strain of PZN-PT single crystals poled along the ^001& direction show little hysteresis and have a linear dependence on the applied field, which is a consequence of engineered domain stability. Hence the dielectric and piezoelectric coefficients of the material do not exhibit any field dependence. However, when the applied electric field exceeds a threshold value, the strain and dielectric responses become nonlinear. The dielectric and piezoelectric constants are a function of the applied field, and hysteresis loops are observed. The results suggest that the observed nonlinear behavior in the PZN-PT single crystals is caused by domain motion/switching in response to the large ac fields. A positive dc bias effectively stabilizes the domain configuration in the crystals and enhances the linear response. The threshold field, at the onset of nonlinearity, is a linear function of the dc bias field in the field range investigated

Methodology

The detailed analytical investigation of wave instabilities in piezoelectric materials with SDDC under a variety of configurations of electric and magnetic fields and the wave vectors. The general dispersion relations will be derived for different type of waves. The general dispersion relations will be derived for different type of waves in the medium using hydrodynamic model of plasmas, Maxwell's equations and coupled mode theory. The electro kinetic branches of the dispersion relation will be examined. The propagation characteristics and the possibility of instabilities will be investigated.

When a crystal is irradiated by any pump field its dielectric constant does not remain constant but does, in fact depends upon the deformation of the material; this is true for both piezoelectrically active as well as inactive crystals.

Thus Simple analysis of the modulation instability of a laser beam in material with strain dependent dielectric constants is given in this thesis. The analysis is based on the hydrodynamic model of the plasma in the collision dominated regime. Using coupled mode theory the acoustic instability in the medium is investigated and the threshold value of the pump electric field and the conditions for the initial growth rates are deduced. It is found that the large value of growth rate can be achieved for materials having an anomalously large dielectric and /or Deformation potential interactions.

Results and Discussion

The results of the analysis for specific piezoelectric materials with SDDC to demonstrate the practical utility of the theoretical investigations proposed to be made we also aim to complete to compare our analytical results with the available experimental results.

Plasma is overwhelmingly the dominant constituent of the universe as a whole. Yet most people are ignorant of plasmas. In daily life on the surface of planet Earth, perhaps the plasma to which people are most commonly exposed is the one that produces the cool efficient glow from fluorescent lights. Neither solid, nor liquid, nor gas, plasma most closely resembles the latter, but unlike gases whose components are electrically neutral, plasma is composed of the building blocks of all matter: electrically charged particle at high energy.Plasma is so energetic or "hot" that in space it consists solely of ions and electrons forming gases. It is only when plasma is cooled that the atoms or molecules, in space, plasma remains electrically charged. Thus plasmas carry electric currents and are more influenced by electromagnetic forces than by gravitational forces. Outside the Earth's atmosphere, the dominant form of matter is plasma, and "empty" space has been found to be quite "alive" with a constant flow of plasma. Plasma is by far the most common form of matter known. Plasma in the stars and in the tenuous space between them makes up over 99% of the visible universe and perhaps most of that which is not visible. On earth we live upon an island of "ordinary" matter. The different states of matter found on earth are solid, liquid, and gas. We have learned to work, play, and rest using these states of matter. Sir William Crookes, an English physicist, identified another, more fundamental, state of matter in 1879. In 1929, Nobel Laureate Irving Langmuir gave this state a name, plasma. He borrowed the term from medical science because the matter with which he worked resembled life itself. It formed cells through bifurcation and often acted in a complicated and unpredictable manner. Plasma is defined as an assemblage of charged particles called electrons and ions that react collectively to forces exerted by electric and magnetic fields

Plasma physicists have also contributed greatly to studies of turbulence, important for safe air travel and other applications. Basic plasma science continues to be a vibrant research area. Recent new discoveries have occurred in understanding extremely cold plasmas which condense to crystalline states, the study of high-intensity laser interactions, new highly-efficient lighting systems, and plasma-surface interactions important for computer manufacturing.

Thus we can conclude that role of plasma physics in service of society is very important

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