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The Study of the Stimulated Raman Process in a Magnetized Plasma and its Effect on Material Deposition, Itching and Cutting

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Abstract

In this work, we consider the interaction of an electromagnetic wave with the collective modes of a magnetized plasma. In the studied process of the stimulated Raman scattering (SRS) in an electron-positron-ion magnetized plasma, an electrostatic wave will accelerate the electrons of the plasma, and this will lead to a separation of charges in the plasma under the effect of this acceleration. This separation of charge will force the ions of this plasma to be accelerated and from this ions acceleration induced by this parametric process SRS, we expect to enhance the level of the process of material itching (or engraving), deposition, and cutting.

§1.1. Introduction

Electron-positron (e-p) plasmas can be found in the early universe, in astrophysical objects such as pulsars, active galactic nuclei, supernovae remnants, in γ-ray bursts and at the center of the Milky Way galaxy [1,2]. These plasmas are created by collisions between particles that are accelerated by electromagnetic and electrostatic waves and/or by gravitational forces. High energy laser-plasma interactions and fusion devices can be used to produce e-p plasmas. Electron-positron plasmas are also created in large tokamaks[3] through collisions between Mev electrons and thermal particles. Due to the mass symmetry in e-p plasmas, there are fewer spatial and temporal scales on which collective effects (e.g, electrostatic and electromagnetic waves as well as their instabilities and coherent nonlinear structures, etc) can occur [1,2]. For instance, Iwamoto [4] has given an elegant description of the linear modes in a non relativistic pair plasma that is magnetized. In addition, Zank and Greaves [5] studied the linear properties of various electrostatic and electromagnetic waves in unmagnetized and magnetized pair plasmas. On the other hand, Bornatici *et al.*[6], Liu and Rosenbluth[7] and Drake[8] studied also the parametric interaction of an intense coherent electromagnetic wave with collective modes in an electron-ion plasma. If the excited waves are both electrostatic, they may be absorbed in the plasma. In contrast, if one of the excited plasma waves is electromagnetic, it can be scattered. This process is called " stimulated Raman scattering" if the excited plasma wave is a Langmuir wave and it is called " stimulated Brillouin scattering" if the excited plasma wave is an ion-acoustic wave. Furthermore, while the unmagnetized plasma may reveal three wave modes, namely, Langmuir, ion-acoustic and electromagnetic modes, the magnetized plasma may support a great number of new wave modes [9]. The basic modes of magnetized plasmas such as those that are found in molecular clouds, cometary plasmas and stellar atmospheres are of a great interest [10] , for instance, Alfvén waves are of importance to the understanding of many basic plasma phenomena [11,12]. It has been shown also that the magnetic field generated in laser-produced plasmas are strong enough to alter the spectrum of electrostatic modes in the plasma but not strong enough to modify the characteristics of propagation of the incident and scattered electromagnetic modes[13]. In the present paper, the stimulated Raman scattering is studied in a magnetized e-p plasma containing a fraction of ions (e-p-i plasma). As a matter of fact, astrophysical and laboratory plasmas contain in general a fraction of ions, e.g, electron-positron-ion plasmas are encountered in the magnetosphere of neutron stars, and also in the solar atmosphere[14-17]. Indeed, these plasmas received some attention from numerous authors[18-19]. The maximum growth rate of the stimulated Raman scattering process is calculated and compared to a previous study. On the other hand, the different technics using plasmas to realize the three processes of itching, deposit, and cutting of materials could be improved by applying the parametric acceleration on the plasmas used in this way (that is the aim of our present work) and this is possible through the stimulated Raman parametric instability (or the Stimulated Raman Scattering SRS). Knowing the high accelerations which can be reached by applying this parametric process on plasmas, we can expect, that the three processes of itching, deposit, and cutting of materials will know a real improvement and this will conduct to a high progress in scientific research and in industry. Such progress will save us enough time and energy and will give us best results and qualities. Knowing the different phenomena occurring in a plasma intended for these three processes of itching, deposit and cutting of materials, we have concluded that the increase of ions acceleration in this plasma will allow us to reach best results and more efficient itching, deposit and cutting of materials. Therefore, in our work, we support the idea that to improve the three processes of itching, deposit and cutting of materials we have to accelerate highly the ions of the plasma using the SRS parametric process. In our work, we have also the aim to evaluate the maximum growth rate of this SRS parametric process and we discuss through this, the importance of the acceleration of the ions of different types of magnetized and unmagnetized plasmas under the effect of SRS parametric process and how this acceleration process will give us more efficient itching, deposit, and cutting of materials. The paper is organized as follows: in Sec.2, we present the essential of our previous theory on the SRS process and we discuss through the results of this theory the possibility to enhance the level of the processes of Itching, deposition and cutting of materials by the use of the SRS parametric process in the acceleration of the ions of the plasma and we conclude in Sec.3.

§.2. Theory

We consider an (e-p-i) plasma embedded in a uniform background magnetic field $\vec{B}_0$. We consider a large amplitude electromagnetic pump wave with an electric field $\vec{E}_t$ parallel to $\vec{B}_0$, where,

$$\vec{E}_t = 2\vec{E}_{t0}\cos\left(\vec{k}_t.\vec{x} - \omega_t t\right), \tag{1}$$

Using the results of Nishikawa [20] and Tinakiche et al [21, 22] and and the expression of the maximum growth rate $\gamma_{\max}$ of the stimulated Raman scattering process found in the work of Tinakiche et al [21, 22], given by:

$$\gamma_{\max(e-p-i)} = \frac{\frac{(1-\delta)}{\sqrt{1+\delta}}\omega_{pe}^2 k_1 |\vec{u}_t.\vec{u}_{t'}|}{4\omega_t\left[\omega_{t'}\,\pi N_{0e^-}\, m\left(\left(\frac{1-\delta}{1+\delta}\right)\omega_{ce}^2 + (1+\delta)\omega_{pe}^2 + \frac{3KT_e}{m}k_1^2\right)^{1/2}\right]^{1/2}} E_{t0} \tag{2}$$

where,

$$\omega_{t'}^2 = k_{t'}^2 c^2 + (1+\delta)\,\omega_{pe}^2$$

We can do the following remarks and conclusions:

a) From Eq.(2) , we see that the maximum growth rate of the parametric instability SRS is effectively proportional to the amplitude of the incident electromagnetic pump wave E_{t0}.

b) On the other hand, by setting $\delta = 0$ (no positrons in the plasma) in the expression of $\gamma_{\max(e-p-i)}$ (c.f.Eq.(2)) we obtain the following expression of the maximum growth rate $\gamma_{\max(e-ion)}$ for an (e-i) plasma given by Eq.(3).

$$\gamma_{\max(e-ion)} = \frac{\omega_{pe}^2 k_1 |\vec{u}_t.\vec{u}_{t'}| E_{t0}}{4\omega_t\left[\omega_{t'sh}\,\pi N_0\, m\left(\omega_{ce}^2 + \omega_{pe}^2 + \frac{3KT_e}{m}k_1^2\right)^{1/2}\right]^{1/2}}, \tag{3}$$

which corresponds exactly to the maximum growth rate of the SRS process calculated by Shivamoggi for an e-ion plasma in Ref.[13],where,

$$\omega_{t'sh}^{2} = k_{t'}^{2} c^{2} + \omega_{pe}^{2}, \qquad (4)$$

The following expression of the ratio $\gamma_{\max(e-p-i)} / \gamma_{\max(e-ion)}$ given by Tinakiche et al [21, 22],

$$\gamma_{\max(e-p-i)} / \gamma_{\max(e-ion)} = (1-\delta)(1+\delta)^{-3/4} \left[1 + \frac{\delta - \left(\frac{2\delta}{1+\delta}\right)\frac{\omega_{ce}^{2}}{\omega_{pe}^{2}}}{\left(1 + \frac{\omega_{ce}^{2}}{\omega_{pe}^{2}} + 3\frac{T_e}{T^{*}}\left(k_1 \lambda_D^{*}\right)^{2}\right)} \right]^{-1/4}, \qquad (5)$$

Allows us to deduce that the ratio $\gamma_{\max(e-p-i)} / \gamma_{\max(e-ion)}$ increases for increasing $k_1 \lambda_D^{*}$, whereas for a given wavelength, the ratio increases with temperature. We find also that the normalized maximum growth rate $\gamma_{\max(e-p-i)} / \gamma_{\max(e-ion)}$ decreases for increasing values of the parameter δ. This tendency has been revealed also from our results reached in our previous work concerning an unmagnetized electron-positron-ion plasma (c.f.Ref.[2]).

c) The increase of the acceleration of the plasma ions through the SRS parametric process will increase surely the velocity and the deep of itching of materials
d) The increase of the acceleration of the plasma ions through the SRS parametric process will increase surely the velocity and the density of the deposition of the thin layers of materials
e) By using a thermal plasma, the heating by the SRS parametric will surely increase the velocity and the thickness of the material cutting.
f) From the above results, we conclude that we have to reduce the magnitude of the magnetic field and the presence of the positrons in the plasma or the parameter δ (the positrons could be created from the Bremstrahlung rays in the plasma) if we want to increase the growth rate of the SRS process. In this way, we will obtain a maximum efficiency of ions acceleration through this process and therefore we improve the process of Itching, deposition, and cutting in materials using such plasmas under the effect of the SRS parametric process. In our work, we consider a very small magnetic

field to take into account of the fact that magnetic field maintains the gaz discharges and the plasmas in the laboratories devices. The other reason concerns the fact that according to Stamper et al [23] experiments, intense spontaneously generated magnetic fields are always present in Laser-produced plasmas and therefore we have to take into account the effect of the magnetic fields in our calculus as it was done in the Eqs. (2) we have obtained in our previous work. An adjustment of the intensity of the laser and the plasma properties (its density and its temperature for example) will reduce the wrong effect of the magnetic field and so will enhance the efficiency of the itching, deposition and cutting of materials.

g) In our work, we have to consider a small ω_{pe} because the SRS parametric process occurs in a plasma with a small density ($N_{0e^-} \leq \frac{Nc}{4}$ with N_c the critical density)

h) We propose in the present work to increase more and more the acceleration of the ions after their acceleration by the SRS parametric process and this by adding a system of electrodes (between the material and the plasma) to increase their acceleration. Through this second acceleration, we hope to enhance more and more the efficiency of the itching, deposit and cutting of materials.

i) We think that the high accelerations of ions reached after this process using the Parametric instability of Raman (or SRS) could be very useful in medicine also as in PROTON- THERAPY and for disinfestation.

§.3. Conclusion

Through the discussion above of the remarks and results, we conclude that the inclusion of the SRS parametric process in the aim to accelerate sufficiently the ions of the plasma will help strongly to improve the processes of Itching, deposition, and cutting of materials. From this fact, we expect a neat improvement in the rapidity, in the quality and in the yield of this three processes of Itching, deposition, and cutting of materials which intervene in several fields as in microelectronics, computer science, in industry and other social and medical interests as in disinfection and proton therapy (elimination of very hard dermatitis and bones problems as bones wrong formation for examples).

AVAILABILITY OF DATA/

Data available in article or supplementary material- The data that supports the findings of this study are available within the article [and its supplementary material].

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