§2. Plasma Density Response Induced by Laser Photodetachment

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Plasmas, which contain negative ions, have been studied in the fields such as astrophysics, negative ion source development, and divertor plasma physics for nuclear fusion. Negative ion diagnostics in plasmas are required to optimize negative ion sources and to understand the production and destruction mechanism of negative ions.

Laser photodetachment technique [1] assisted with Langmuir probe is considered to be most useful as a diagnostic tool of negative ions in plasma. In addition to negative ion densities, negative ion temperatures can be obtained by this technique with the help of the ballistic theory [2]. However this technique has been applied, only when a Langmuir probe is placed onto a laser axis.

Perturbed densities both inside and outside the laser beam are analyzed using the hybrid fluid-kinetic model [3]. We extend this model to analyze an entire plasma response at r, where r is the distance from a laser axis, using the general solutions of $\delta n_e(r, t)$ and $\delta n_-(r, t)$ until the plasma recovers to the original condition. The results are compared with the typical experimental data in order to confirm the hybrid fluid-kinetic model.

When v_{th}^- is the thermal velocity of negative ions, R the laser radius, k the wave number, T_e electron temperature, and T_+ positive ion temperature, we introduce the following dimensionless quantities:

$$x = v/v_{th}^- \,;\, \tau = v_{th}^- t/R \,;\, \alpha = \sqrt{\gamma T_+/T_e} \,;\, \eta = r/R \,;\, \xi = kR\,.$$

Then the density perturbation for electrons is given by:

$$\frac{\delta n_e(\eta,\tau)}{n_{-0}} = \frac{2}{\sqrt{\pi}}\int_0^{+\infty}\frac{\Psi(\eta,\sqrt{1+\alpha^2}\,\tau)-(x^2-\alpha^2)\Psi(\eta,x\tau)}{1+\alpha^2-x^2}\,e^{-x^2}dx, \quad (1)$$

$$\Psi(\eta,x\tau) = \int_0^{\infty}\cos(x\tau\xi)J_0(\eta\xi)J_1(\xi)\,d\xi\,,$$

with the first kind Bessel function of the order 0 and the order 1. Then we assumed $kT_-/M=(v_{th}^-)^2$. This assumption is reasonable for the experimental results given in Ref. [4], which show the ion acoustic velocity for H_3^+ is very close to v_{th}^-, and thus leads to the condition of $T_e/T_-=24/\pi$.

For negative ions, the perturbation is given by

$$\frac{\delta n_-(\eta,\tau)}{n_{-0}} = \int_0^{+\infty} J_0(\eta\xi)\,J_1(\xi)\,e^{-(\tau\xi/2)^2}d\xi\,. \quad (2)$$

Figure 1 shows the comparison between the calculations and the experiments. At $\eta(=r/R)=0$(upper graph), the perturbed electron densities are calculated for typical three values of α. In this case the calculation with $\alpha = 0.59$ reproduces the experiment, and then we can obtain $T_+=0.1$eV. In the lower graph, the perturbed electron density is reproduced well at $\eta=1.6$(r=4mm). The same results are obtained at the further distance, $\eta=2.0$ and 2.4.

In view of negative ion diagnostics, it is found that the hybrid fluid-kinetic model is effective in our experimental conditions.

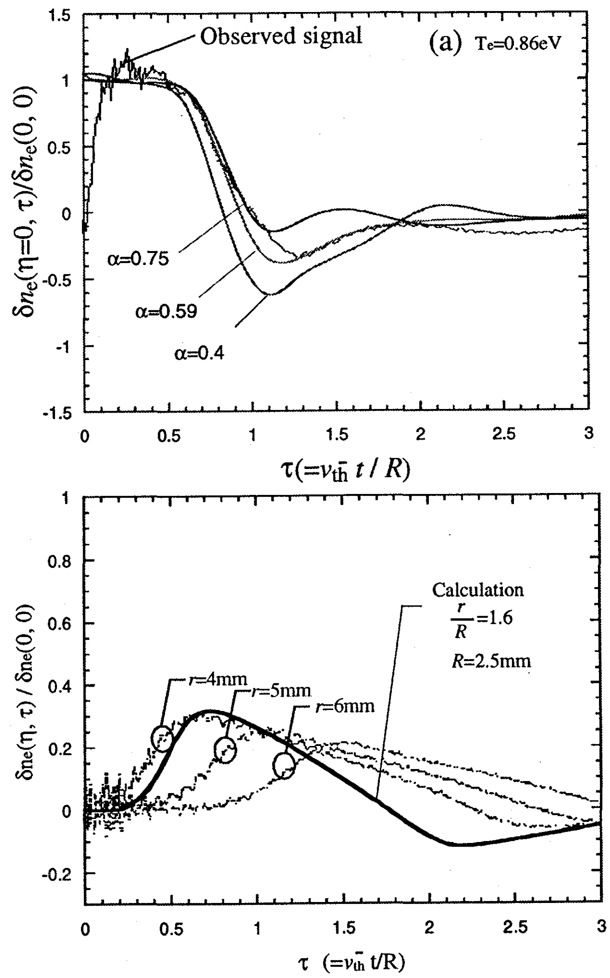

Fig. 1. Typical observed signals of excess electron current due to photodetachment are compared with calculated curves at the normalized distance η(r=0, upper graph), and $\eta=1.6$(r=4mm, lower graph).

References

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