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Magneto-Kerr Effect at a Plasma Surface

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Reflection at an anisotropic plasma surface changes the polarization of an electromagnetic wave from linear to elliptical. This magneto-Kerr effect is calculated and detected experimentally when two orthogonal components of a reflected microwave beam are studied.

RECENTLY in this Laboratory we studied the reflection of a linearly polarized microwave beam from the surface of an anisotropic plasma,[1] and showed how the observation of the wave component reflected with the same polarization (which we shall now call the "vertical" polarization) could follow the decay of surface electron density. We used a plasma surface oriented at right angles to a strong magnetic field. Our procedure for calculating the dependence of reflectivity on the plasma parameters was to resolve the incident plane-polarized wave into left- and right-hand circularly polarized components and consider their reflections separately. The two circulating waves are reflected differently not only in phase but also in amplitude so that, in general, the reflected wave is elliptically polarized.

While in our previous work we compounded these circularly polarized reflected waves to calculate, and observe, only one linearly polarized component, we have now observed and compared with theory, two orthogonally polarized components—one with "vertical" and one with "horizontal" polarization. The experimental measurements are in good agreement with the theoretically predicted components of the elliptically polarized reflected wave. It is believed that this is the first observation of the magneto-Kerr effect at the surface of a laboratory plasma.

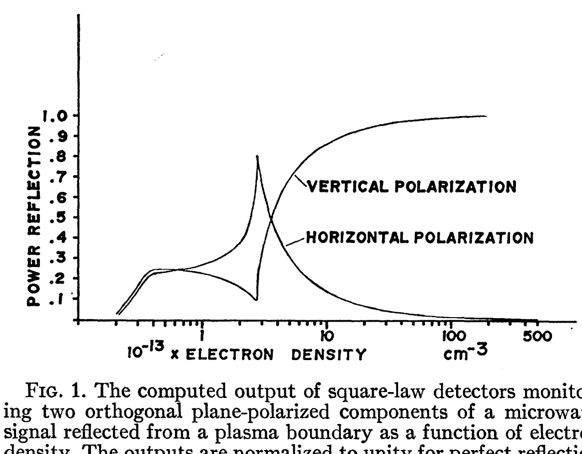

FIG. 1. The computed output of square-law detectors monitoring two orthogonal plane-polarized components of a microwave signal reflected from a plasma boundary as a function of electron density. The outputs are normalized to unity for perfect reflection of the wave component polarized "vertically," that is, in the same plane as the incident wave. The plasma surface is assumed a step function of density oriented perpendicular to a 10-kG magnetic induction field, the microwaves propagating parallel to this field.

For the vertical polarization the predicted dependence of reflected power on plasma surface electron density can be calculated from the equations published previously.[1] For an assumed collision frequency $\nu = 10^9$ sec^{-1}, and for 35-Gc/sec microwaves the computation gives the appropriately labeled curve in Fig. 1. The horizontal polarization can be calculated by a similar procedure; the result is also plotted in Fig. 1, while the ratio of these two curves is plotted in Fig. 2. The curves are not substantially different from those for a collisionless plasma. If we separately monitor the power in the two components of the elliptically polarized wave reflected from the surface of a magnetized plasma, decaying in time through the appropriate density range, we expect the vertically polarized reflection to be large initially and to decrease as the density falls. On the other hand, the horizontally polarized reflection will be small initially and rise to a peak at a later time when the electron density has decreased to the vicinity of 2.7×10^{13} cm^{-3}.

We have carried out an experiment along these lines using, as in our previous experiment, a hydrogen plasma in the SUPPER I plasma source at Sydney University, irradiating the plasma surface through a thick glass window with microwaves from a horn antenna. The arrangement is shown schematically in Fig. 3. It differs from that in our previous experiments in that a microwave fin-line[2] is used to separate the two polarizations. This component is, in fact, used reciprocally: The rectangular waveguide from the

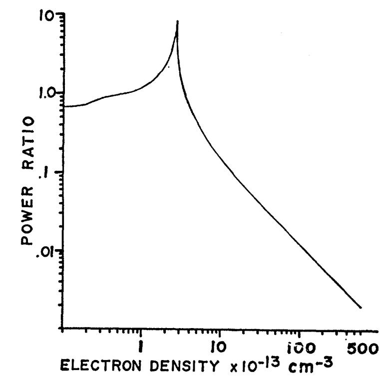

FIG. 2. Ratio of the horizontally to vertically polarized reflected power curves of Fig. 1.

[1] L. C. Robinson, J. Nucl. Energy 7, 167 (1965).

[2] S. D. Robertson, IRE Trans. Microwave Theory Tech. MTT-4 263 (1956).

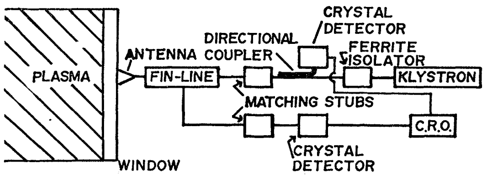

FIG. 3. Schematic diagram of the microwave reflection experiment.

klystron generator is tapered up to the square waveguide of the fin-line, the wave propagating through the fin-line and horn antenna (which has a square-waveguide aperture) towards the plasma. After reflection the vertically polarized wave returns back through the system and through the directional coupler to a square-law detector, while the horizontally polarized wave is separated into the side-arm waveguide of the fin-line with its square-law detector. Thus each of the crystal detectors displays the power in one of the two linearly polarized waves which are of interest.

Oscilloscope traces of the crystal output currents obtained in this experiment are shown in Fig. 4. During the first 80 μsec of the oscilloscope display the plasma surface from which the wave is being reflected is in the process of formation; its buildup follows the passage of a magnetohydromagnetic ionizing front along the cylindrical plasma vessel towards the glass window closing the vessel.[3] After this time the plasma decays

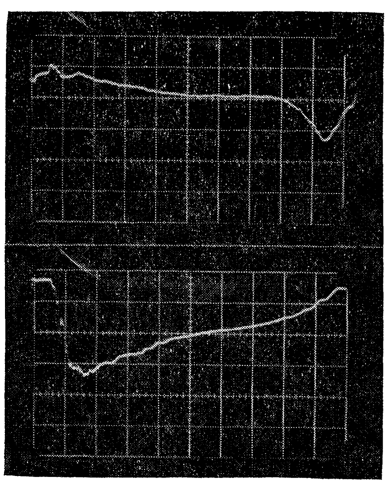

FIG. 4. Oscilloscope records of microwave reflected power signals (deflection downwards) on a time scale of 50 μsec/div. The upper trace is the horizontal and the lower the vertical polarization.

[3] G. F. Brand, S. K. Chung, and L. C. Robinson, Nucl. Fusion (to be published).

in density. We see that the reflected power in both polarizations behaves much as we have predicted: The vertically polarized reflection decreases while the horizontally polarized reflection increases smoothly from small initial values through a peak at 470 μsec. The two reflections are quantitatively consistent. From the ratio of the powers measured in the two polarizations (it should be noted that to compensate for the effect of the different microwave paths the horizontally polarized signal in Fig. 4 must be reduced by 6.9 dB) we can estimate the electron density from the theoretical ratio curve of Fig. 2. This procedure has given density-decay curves in good agreement with our previous determinations.[1] Even at the late time of 470 μsec this procedure gives a density of 3.8×10^{13} cm^{-3}, which checks reasonably well with the value 2.7×10^{13} cm^{-3} for the occurrence of the maximum in our theoretical curve for the horizontal polarization. Our calculations show that this peak occurs near $\omega_p^2=\omega(\omega+\omega_{be})$, ω_p, ω, and ω_{be} being respectively the plasma, microwave, and electron cyclotron frequencies, and that for higher collision frequencies its magnitude decreases below the value in Fig. 1.

Because of the development of a radial density profile in our plasma source we are able to reflect waves from elements of the surface with different decay rates. Near to the cylindrical plasma boundary the condition $\omega_p^2=\omega(\omega+\omega_{be})$ will be reached earlier. Consistently with this we find that the peak in the observed horizontal polarization is reached at progressively earlier times as our point of observation is moved radially outwards.

In summary, then, the similarity of the observed waves with the calculated components of the reflected elliptically polarized wave demonstrates the magneto-Kerr effect at the plasma surface. It is anticipated that the exploitation of this effect can provide useful information about plasma surfaces. In particular, as the ratio of the orthogonally polarized signals does not involve normalization to perfect reflection, the effect makes possible the absolute determination of surface electron density.

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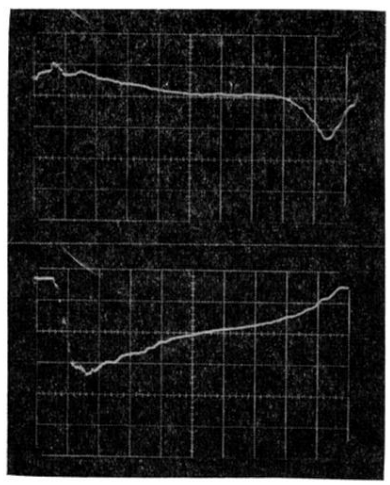

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