LABORATORY MODELING OF SPIKE-LIKE OPERATION OF SPACE CYCLOTRON MASERS*

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ABSTRACT

We study pulsating regimes of whistler cyclotron instability in a laboratory magnetic mirror trap filled with the ECR plasma having anisotropic ($T_\perp > T_\parallel$) hot-electron (5 to 100 keV) population. Quasi-periodic spikes of precipitated energetic electrons are detected simultaneously with the whistler-mode electromagnetic emission propagating quasi-parallel to the magnetic field. We identify electron precipitation mechanism as the turbulent diffusion at whistler-mode waves generated by the cyclotron instability of energetic electrons. These spike-like precipitation regimes are consistent with the theory of cyclotron masers and have much in common with similar regimes in space objects, in particular, in magnetospheric radiation belts and solar flaring loops.

The dynamics of energetic charged particles and waves in magnetic mirror traps in both laboratory and space can be significantly affected by operation of cyclotron masers, in which the trapped energetic particles serve as an active substance and the inhomogeneously distributed plasma forms waveguides and resonators for working wave modes. Space and laboratory cyclotron masers have many similarities, since their regimes are determined by the same set of basic linear and nonlinear mechanisms. On the other hand, space and laboratory plasmas have very different parameters and, hence, the maser regimes can exhibit not only quantitative but even qualitative differences. Therefore, comprehensive studies of such regimes in both space and laboratory experiments and cross-comparison of the results will allow us to achieve deeper understanding of plasma dynamics in a wide range of parameters.

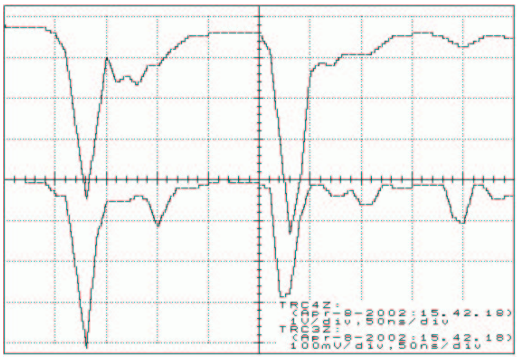

Fig. 1. Synchronous detection of precipitated energetic electrons (upper curve) and microwave radiation in the range 5.4–8.1 GHz (lower curve). Temporal scale is 50 ns/div.

Quasi-periodic spikes of precipitated energetic electrons are detected by the current pulses produced by these electrons hitting semiconductor detectors (pin-diodes) at the ends of the trap. Associated with these spikes is the electromagnetic emission propagating quasi-parallel to the magnetic field. The emission spectrum is bounded from above by the frequency which is below the electron gyrofrequency in the central cross-section of the trap.

We study the dynamics of pulsating regime as dependent on the ambient gas pressure, power of the heating pulse, mirror ratio, and the position of the gyroresonance level for the heating radiation with respect to the trap center. Several mechanisms of spike formation are considered. In particular, we discuss the role of wave reflection at the ends of the plasma column, heating of background plasma by the excited radiation, and nonlinear modification of the hot-electron distribution function. Cold plasma profile across the magnetic field is found to influence significantly the radial distribution of spikes which can be attributed to the discrete mode structure of whistler waves guided by plasma column.

We identify the electron precipitation mechanism as the turbulent diffusion at whistler-mode waves generated by the cyclotron instability of the energetic electrons. The spikelike regimes observed in experiment can be consistently explained in terms of electron cyclotron maser theory.

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