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In this program, we have identified theoretically the most promising candidate for current driven plasma instabilities (CDPI) in semiconductor based systems: *the modulated lower dimensional systems*. We also investigated the effects of a grating coupler and a strong magnetic field on CDPI in uniform two-dimensional electron gases. Significant progress was made in pursuing the goal of experimental verification of this phenomenon in superconductor based systems.

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I. Introduction

In this program we have identified a new promising system for the experimental verification and device applications of current driven plasma instabilities (CDPI) in solid state systems. This system is based on the idea of *periodic modulation* of the carrier density, which can be achieved by applying a periodic grid (grating) over the lower dimensional system (2DEG or 1DEG). We have investigated the effects of an un-biased grating on the underlying uniform 2DEG, as well as, the effects of a biased grating which imposes the periodic modulation. We have also continued investigation of the superconducting system in close collaboration with an experimental group. We have also studied the effect of strong magnetic field on the CDPI in a uniform 2EDG.

Section II provides a statement of the problem studied, section III summarizes the most important results and the last section lists all publications, and participating scientific personnel.

II. Statement of the Problem

The basic problem investigated in this program was a study of CDPI in solid state systems, leading to a novel approach for generation or amplification of electromagnetic radiation in the millimeter and submillimeter ranges, with potential applications to a new class of devices.

The basic principle is to utilize the energy of a dc current passing through a plasma, which leads to a plasma-instability. The instability mechanism transfers the energy from the current to characteristic plasma waves which grow in amplitude. These waves, in turn, can radiatively decay under an appropriate set up, emitting electromagnetic radiation in a predictable frequency range.

In an earlier program we had studied high mobility, lower dimensional, *uniform* systems as the solid state media for achieving CDPI, since they offer reduced carrier scattering effects and high carrier drift velocities. The required drift velocities had to be of the order of, or greater than the Fermi velocities. While this is achievable in principle in very high quality samples, there are significant practical difficulties in realizing workable systems. Our main goal in the present program was to come up with a new approach to overcome these difficulties. The modulated systems mentioned above, under appropriate conditions, require an order of magnitude smaller driving electric fields, and would thus solve this problem.

III. Main Results.

There were four major topics covered in this program. We summarize below the main results:

1. Effects of grating couplers on uniform layered systems

There are two main effects due to the grating: (i) The dispersion relation of *pre-existing modes* is altered by the presence of the grating. (ii) A new *grating generated mode* was discovered, and its instability understood in terms of a resistive wall instability. Details of this work were published as Ref.1. We obtained the efficiency of conversion of the plasma wave energy to electromagnetic radiation in all cases, which increases as the grating is brought closer to the unstable system. For the pre-existing modes, however, bringing the grating too close quenches the mode. In contrast, the grating generated mode is enhanced by the proximity of the grating. This study suggested that a grating generated instability is preferable, since both the intrinsic instability and the conversion efficiency can be simultaneously enhanced. We note here that using a modulated system (which can be viewed as a grating directly "built-into" the electron system) accomplishes this.

2. Modulated systems

We have pointed out earlier that the difficult experimental problem of attaining the drift velocities two or three times the Fermi velocities can be circumvented if we use modulated electron gas systems. A periodically modulated system with a small population in the highest mini-band acts as an electron gas with an effective Fermi velocity much smaller than the Fermi velocity of the unmodulated system of the same density. Consequently, a much smaller drift velocity (and a correspondingly smaller driving electric field) suffices to produce the plasma instability. We have investigated this phenomenon in detail (see Ref.2) for a model system consisting of a 1DEG with a periodic density modulation. Confining our system to a 2-miniband model we obtained the growth rates of CDPI for various driving field strengths. The main conclusion was that the modulated system gives rise to a strong instability at field strengths which are an order of magnitude smaller than those required for the corresponding unmodulated system. We also showed that the underlying physical principle for this instability was the creation of a velocity gap in the effective distribution function. Since this feature can be shown to survive for other lower dimensional systems, we have established that this is a very promising practical approach to achieve CDPI.

3. Efforts towards experimental verification of CDPI in superconductors

We have continued our very productive interaction with Dr. Michael Graf who has developed an experimental program to verify CDPI in superconductors. He has shown (see Ref.3) that a dissipation of energy of the current occurs which can be explained in terms of our theory of CDPI in a pair of superconductor layers (see Ref. 4). We have further investigated the effects of variable density in the transition layer, which would provide a closer approximation to the physical system. A joint paper with Dr. Graf has been accepted for publication (see Ref.5).

4. Effects of a strong magnetic field.

We have also investigated CDPI in the presence of a strong magnetic field. Rationale for this study was to take advantage of the dissipationless environment of the quantum Hall effect regime. We find that a strong CDPI can be generated for drift velocities corresponding to carrier kinetic energy exceeding the Landau level separations. This work (Ref.6) will be submitted for publication in near future.

In conclusion, we have now identified theoretically the most promising candidate for CDPI in semiconductor based systems: *the modulated lower dimensional systems.* Future work along those lines can be expected to lead to specific determination of the best system parameters to bring this phenomenon within the reach of experimental verification. We have also made significant progress in pursuing the goal of experimental verification of this phenomenon in superconductor based systems.

References for Section III

1. K. Kempa, P. Bakshi , H. Xie, and W.L. Schaich, " Current driven plasma instabilities in solid state layered systems with a grating", Phys.Rev.B 47, 4532, (1993).
2. K. Kempa, P. Bakshi and H. Xie, "Current-driven plasma instabilities in modulated lower-dimensional systems", Phys. Rev. B48, 9158, (1993).
3. F. Dong, M.J. Graf, and P.M. Mankiewich, "Experimental search for current driven plasma instabilities in superconducting layers", Solid State Comm. 84, 785-788, (1992)
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5. M.J. Graf, P. Bakshi, F.Dong, and K. Kempa, "Current driven plasma instabilities in superconducting systems", (accepted for publication in Physica B, 1993).
6. P. Bakshi and K. Kempa, "Current driven plasma instabilities in strong magnetic fields", (to be published).

IV. Publications and Personnel.

a) Publications

1. K. Kempa, P. Bakshi , H. Xie, and W.L. Schaich, " Current driven plasma instabilities in solid state layered systems with a grating", Phys.Rev.B 47, 4532, (1993).
2. K. Kempa, P. Bakshi and H. Xie, "Current-driven plasma instabilities in modulated lower-dimensional systems", Phys. Rev. B48, 9158, (1993).
3. M.J. Graf, P. Bakshi, F.Dong, and K. Kempa, "Current driven plasma instabilities in superconducting systems", (accepted for publication in Physica B, 1993).
4. P. Bakshi and K. Kempa, "Current driven plasma instabilities in strong magnetic fields", (to be published).

b) Personnel

1. P. Bakshi (Faculty), Principal Investigator
2. K. Kempa (Faculty), Principal Investigator
3. H. Xie (Research Assistant)

c) Degree earned.

none

d) Reportable inventions.

None