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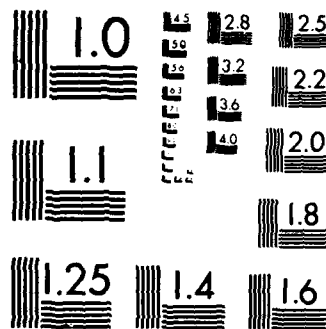   E GORNIK ET AL   30 JUN 86 DAJA45-84-C-0052
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-novel tunable FIR sources
-hot electron emission in GaAs/GaAlAs heterostructures
-streaming of hot carriers in crossed electric and magnetic fields
-new theory for Landau level inversion by electrical pumping in crossed electric and magnetic fields

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

see reverse side

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Sub μm sinusoidal gratings were prepared on GaAs/GaAlAs heterostructures. Experiments to demonstrate a Smith-Purcell-effect in a semiconductor are in preparation. FIR emission due to streaming of hot carriers in crossed electric and magnetic fields has been observed on large p-Ge samples. Stimulated emission has not been achieved yet. A new theory of the crossed field configuration (electric and magnetic) describing the Landau levels in a quantum mechanical manner was developed. It is shown that population inversion between Landau levels can be achieved, if scattering by optical phonons and a quasielastic scattering process are taken into account.

"HOT ELECTRON EMISSION IN SEMICONDUCTORS"

4th Interim Report
1 Dec. 1985 - 30 June 1986

Summary of the scientific work

The research work on "Hot Electron Emission in Semiconductors"
was continued with the following topics:

a) The emission due to the interaction of drifting carriers
   in GaAs/GaAlAs heterostructures with a periodic grating

b) FIR emission due to streaming of hot carriers in crossed
   electric and magnetic fields in p-Ge

c) Development of a new model for a streaming induced
   population inversion between Landau levels

ad a) With the help of a reactive ion etching (RIE) process
   the surface of GaAlAs/GaAs heterostructures is sinusoidally
   modulated. Through the control of process parameters the
   profile and height of the modulation can be varied between
   50 and 500 $\mathring{A}$. The periodicity is variable between 0.18
   and 0.7 μm due to the laser holographic technique (HeCd
   UV Laser λ = 325 nm). The first goal of the presently
   running experiments is the observation of laterally modu-
   lation 2D-density in the GaAs-channel due to the modulated
   GaAlAs thickness. The next step is the application of an
   electric field to achieve a carrier drift. In high mobility
   samples ($\mu_{4.2K}$ $\sim$ 1.2 x 10^6 cm^2/Vs) a drift velocity of
   1.5 x 10^7 cm/s can be achieved with moderate electric fields /1/.

The observation of far infrared radiation due to the drift of a modulated densit; distribution is the main goal of this part of the project.

At present we are not able to observe any radiation due to this effect which is known in the literature as Smith-Purcell effect /2/. To understand the lack of radiation we have performed calculations in the classical limit /3/: The far infrared radiation of a drifting modulated electron plasma was calculated to 100 pW/cm^2 if the only mechanism for radiation generation is the induced image potential. However, if the induced image potential is amplified by the grating which dynamically influences the electron distribution back, intensities of up to 100 mW/cm^2 become possible. Whether these amplification mechanisms can be induced depends critically on the form of the grating and the distance from the channel. At present we are processing samples to control the etch rate in an anodic oxidation process on the scale of 10 Å.

b) The aim of this part of the project is to investigate the FIR emission from hot holes in p-Ge under crossed field (E $\perp$ B) conditions, and, if possible, develop a coherent far infrared source.

There was not too much progress in this part of the project. According to most recent publications /4,5/ the necessary sample sizes are considerably larger than we have used them. We have prepared in the meantime a sample 2 cm long and 2 x 2 mm^2. With this sample and a new pulse generator which provides peak pulse powers of 100 kW we hope to be able to achieve the lasing condition. The physics of this laser operation is not well understood yet.

In the future we want to investigate the time- and spectral dependence of the stimulated emission and demonstrate spectroscopic applications.

Russian authors claim to achieve peak powers in the far
infrared of up to 10 W, which would enable even nonlinear
spectroscopy.

ad c) In crossed electric and magnetic fields not only a population
inversion between the light and heavy hole band of p-Ge can
arise, but also an inversion between Landau levels in a pure
semiconductor has been predicted /6/. This inversion is
based on the interaction of the electrons with optical phonons,
and should appear when $\zeta = v_{op}B/E \lesssim 2$. Up to now this process
was described qualitatively in the streaming motion picture.
Monte Carlo /7/ and Boltzmann equation /8/ studies also led
to an inverted distribution function. All theoretical investi-
gations of this problem in the past were performed in the limit
of a non-quantizing magnetic field. If one wants to study
optical transitions between (inverted) Landau levels, however,
it is of fundamental importance to consider the discrete
structure of the energy levels.

We have treated the crossed field situation in a fully
quantum mechanical frame, which means that we start from the
Liouville equation for the density operator /9/. In the case
of weak electron-phonon coupling this can be transferred
into a master equation for the diagonal elements of the
electron density matrix /10/ which correspond to the occupa-
tion numbers of the different Landau levels. We have neglec-
ted the dependence of the quantum number k_z, as a consequence
the system of coupled integral equations is simplified to
algebraic equations. This is solved for three Landau levels
taking into account the scattering by optical and acoustic
phonons.

A central result of our calculation is that a quasielastic
scattering mechanism (like acoustic phonon scattering) is
necessary to achieve population inversion. This stands in
contrast to previous calculations performed in the limit of

non-quantizing magnetic field. Further it turns out that inversion is not restricted to $\zeta \approx 2$, but can also occur at somewhat smaller or larger values of ζ. These features seem to be a direct consequence of the discrete structure of the energy spectrum.

It is planned to extend this promising model by including the k_z-dependence and more than three Landau levels.

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R. Christanell

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12 - 86

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