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Interaction of surface acoustic waves with a two-dimensional electron system in a $LiNbO_3$-GaAs/AlGaAs sandwich structure

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A. Wixforth, J. Scriba, M. Wassermeier, et al.

with electron concentration. The peak wavelength of PL spectra decreases with increasing electron concentration due to the Burstein–Moss shift and the band-tailing effects.

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Interaction of surface acoustic waves with a two-dimensional electron system in a $LiNbO_3$-GaAs/AlGaAs sandwich structure

A. Wixforth, J. Scriba, M. Wassermeier, and J. P. Kotthaus
Institut für Angewandte Physik, Universität Hamburg, D-2000 Hamburg 36, Federal Republic of Germany
G. Weimann and W. Schlapp
Forschungsinstitut der Deutschen Bundespost, D-6100 Darmstadt, Federal Republic of Germany

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We describe a simple, contactless method to study the interaction of surface acoustic waves (SAW) with a two-dimensional electron system (2DES) in GaAs/AlGaAs heterostructures at low temperatures and in high magnetic fields. The heterostructure is part of a sandwich structure on a Y-cut Z-propagating $LiNbO_3$-SAW-delay line. The interaction of the SAW with the 2DES leads to quantum oscillations of the SAW amplitude as a function of the applied magnetic field which can be used to characterize the sample and to investigate the transport properties of the 2DES.

In recent reports[1,2] we presented the first experimental results on the interaction of surface acoustic waves (SAW) with a two-dimensional electron system (2DES) in GaAs/AlGaAs heterostructures at low temperatures ($T \lesssim 4.2$ K) and in high magnetic fields ($B \gtrsim 10$ T). We showed that the interaction can be described in terms of a relaxation-type interaction between the mobile carriers in the 2DES and the SAW-electric field, which accompanies the mechanical wave on a piezoelectric substrate. We have also demonstrated that the transport properties of the 2DES can be affected by the strong electric field of the SAW.[2] These changes might give some insight into hot-carrier phenomena as well as the breakdown of the quantum Hall effect.

Here, we report a new, relatively simple contactless technique for such experiments, which circumvents the quite difficult preparation of SAW transducers on the heterostructure containing the 2DES. For this purpose, we use a sandwich system consisting of a SAW delay-line prepared on $LiNbO_3$ and the semiconductor heterostructure under investigation. The electric field of the SAW propagating on the $LiNbO_3$ delay-line decays on a length scale of about one SAW-wavelength into the substrate and the semiconductor located above it.[3] Interaction between this field and the 2DES can occur if the distance between both is smaller than a wavelength.

Sandwich structures with different media using $LiNbO_3$

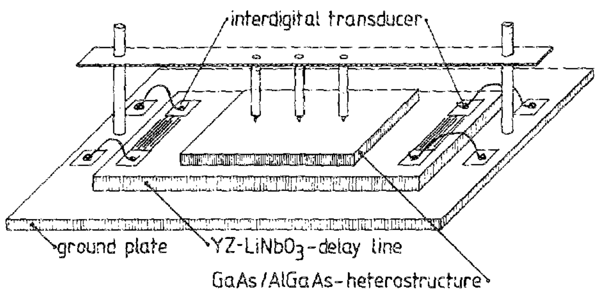

FIG. 1. Sketch of the sample and sample-holder. The heterostructure is mechanically pressed against the surface of the YZ-$LiNbO_3$ delay line. Since the 2DES is only 100 nm away from the interface and the gap between delay line and sample is estimated to be of the order of a few microns, the electric field accompanying the SAW can easily penetrate into the sample.

as the piezoelectric substrate have in the past been employed to study various acoustoelectric effects as convolution,[4] measurements of the surface mobilities of different materials,[5] acoustoelectric effects in superlattices[6] and for the characterization of semiconductor properties.[7] In the case of a 2DES under quantum conditions we have shown[1] that the attenuation of a SAW passing the 2DES is given per unit length by

$$\Gamma = \frac{K^2}{2} k \frac{(\sigma_{xx}/\sigma_m)}{1 + (\sigma_{xx}/\sigma_m)^2}, \tag{1}$$

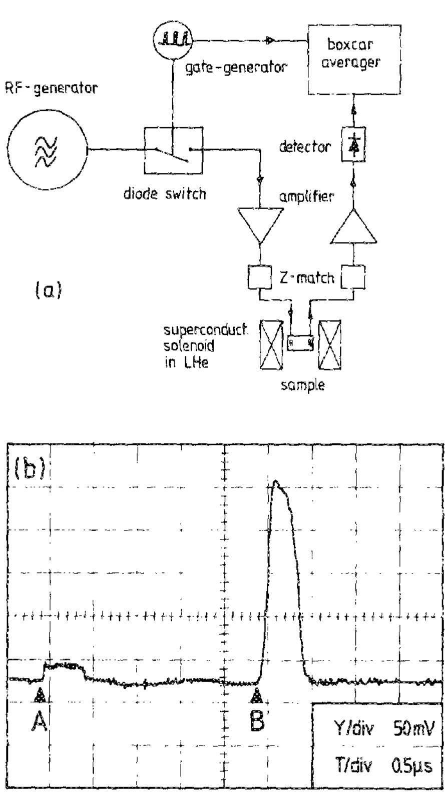

FIG. 2. (a) Experimental setup for SAW experiments. The sample is located in the center of a superconducting solenoid, which provides magnetic fields up to 12 T. A standard boxcar technique is used for measuring the SAW amplitude. (b) Oscilloscope trace of a typical SAW-receiver signal. The rf burst is applied to the emitting transducer at A, after $\sim 2.5\ \mu s$ at B a SAW signal is detected. The structure around A is the electromagnetic pick-up of the pulse in the detection system due to imperfect shielding.

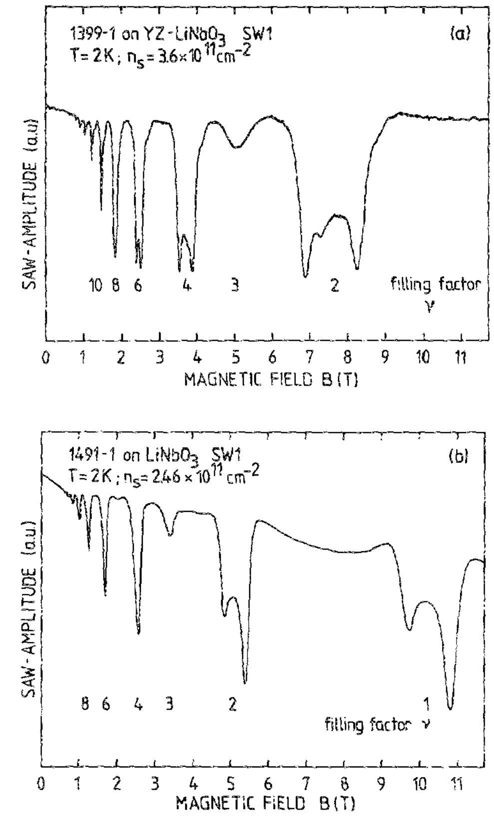

FIG. 3. (a) Typical result for the SAW amplitude as a function of the applied magnetic field B for a sample with carrier density $n_s = 3.6\times 10^{11}$ cm^{-2}. The SAW amplitude shows characteristic quantum oscillations, which reflect the oscillations of the magnetoconductivity σ_{xx}. (b) The SAW amplitude as a function of the magnetic field B for a sample with lower carrier density $n_s = 2.46\times 10^{11}$ cm^{-2}.

where K^2 is the electromechanical coupling coefficient of the specific substrate, cut and propagation direction of the SAW and $k = 2\pi/\lambda$ the SAW wave vector. σ_{xx} is the magnetoconductivity of the 2DES and σ_m a characteristic conductivity where maximum attenuation occurs, given by

$$\sigma_m = v_0(\epsilon_1 + \epsilon_2)\,. \tag{2}$$

Here v_0 is the Rayleigh velocity of the SAW and ϵ_1,ϵ_2 are the dielectric constants of the media below and above the interface, on which the SAW is propagating. Application of a magnetic field perpendicular to the plane of the 2DES leads to the well-known Shubnikov–de Haas oscillations in the conductivity σ_{xx} of the 2DES.[8] These oscillations are reflected in oscillations of the SAW amplitude via Eq. (1).

In Fig. 1 we show a sketch of the sample arrangement used in our experiments. A sample of YZ-$LiNbO_3$ (10×5 mm^2) is used as the delay line. Interdigital transducers consisting of 25 fingerpairs having equal overlap and spacing are used to launch and detect the SAW with $\lambda = 33\ \mu m$. The transducers are separated from each other by 8.5 mm, leading to a total delay time of about 2.5 μs. A heterostructure is located face down on top of the delay line, where it is mechanically pressed against the substrate. Since we take no special care to achieve a well-defined spacing between the $LiNbO_3$ substrate and the heterostructure, we do not expect to be able to reliably describe the absolute damping. If desired, a defined spacing could be achieved by using, e.g., evaporated spacers of known thickness. Figure 2 shows the experimental setup and a typical SAW receiver signal. Short wavepackets (0.5–1 μs) are generated at a frequency of about 100 MHz with a repetition rate of about 1 kHz. Standard boxcar techniques provide the recording of the SAW amplitude as a function of the applied magnetic field B.

Experimental results for the magnetic field dependence of the SAW amplitude are shown in Figs. 3(a) and 3(b) for two samples with different carrier densities n_s and mobilities μ. The quantum oscillations of the SAW amplitude are clearly resolved for magnetic fields higher than about 1 T. They split into two distinct minima under quantum Hall conditions, i.e., if the magnetoconductivity σ_{xx} drops to very low values which are lower than the conductivity σ_m. We attribute the asymmetry of the splitting, which is not predicted by Eq. (1), as well as the structure around filling factor $\nu = 2$ in Fig. 3(a) to spatial inhomogeneities of the carrier density n_s in the heterojunction and will discuss it elsewhere. All the results for the sandwich structure show the same characteristic behavior as observed in Ref. 1 where the SAW was excited directly on the heterostructure sample and show that this new technique can serve as a useful alternative method.

In summary, we describe a simple contactless method for the investigation of the interaction of a SAW with a 2DES. The technique works very well with standard GaAs/AlGaAs heterostructures, which are not specially prepared for this type of experiment. It allows a direct comparison of different samples under the same conditions.

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Monolithic integrated photoreceiver for 1.3–1.55-μm wavelengths: Association of a Schottky photodiode and a field-effect transistor on GaInP-GaInAs heteroepitaxy

A. Hosseini Therani, D. Decoster, and J. P. Vilcot
Centre Hyperfrequences et Semiconducteurs, Unité Asociée au Centre National de la Recherche Scientifique 287, Universite des Sciences et Techniques de Lille-Flandres-Artois, 59655 Villeneuve d'Ascq Cedex, France

M. Razeghi
Laboratoire Central de Recherche, Thomson-CSF Domaine de Corbeville, 91401 Orsay Cedex, France

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We present a monolithic integrated circuit associating a Schottky photodiode and a field-effect transistor which has been fabricated, for the first time, on $Ga_{0.49}In_{0.51}P/Ga_{0.47}In_{0.53}As$ strained heteroepitaxial material. Static, dynamic, and noise properties of the Schottky photodiode, the field-effect transistor, and the integrated circuit have been investigated and are reported. As an example, dynamic responsivity up to 50 A/W can be achieved at 1.3-μm wavelength for the integrated photoreceiver. The performance of the device is discussed, taking into account the integrated circuit design and the main characteristics of the material.

Planar monolithic integrated photoreceivers are desirable devices for optical communication systems. For the 1.3–1.55-μm wavelength range, GaInAs lattice matched to InP is a potentially important material, but the Schottky barrier height on GaInAs is too low to make, for example, field-effect transistor (FET) gates. Various solutions have already been proposed such as the use of $Al_{0.48}In_{0.52}As/Ga_{0.47}In_{0.53}As$, $GaAs/Ga_{0.47}In_{0.53}As$, or GaAs/InP heteroepitaxies.[1–7] Recently, photoreceivers implemented using a *p-i-n* photodiode and a junction field-effect transistor[8] or a metal-insulator-semiconductor field-effect transistor[9] amplifier have been reported. Nevertheless, we think that the use of a metal-semiconductor field-effect transistor as an amplifier stage could more easily lead to submicron devices. This is the reason why we present the first fabrication of an integrated photoreceiver consisting of a Schottky photo-

