Interaction of surface acoustic waves with a two-dimensional electron system in a LiNbO$_3$-GaAs/AlGaAs sandwich structure

Cite as: Journal of Applied Physics 64, 2213 (1988); https://doi.org/10.1063/1.341685
Submitted: 22 December 1987 • Accepted: 15 April 1988 • Published Online: 04 June 1998


ARTICLES YOU MAY BE INTERESTED IN

Giant acoustoelectric effect in GaAs/LiNbO$_3$ hybrids
Applied Physics Letters 73, 2128 (1998); https://doi.org/10.1063/1.122400

Acoustically induced current flow in graphene
Applied Physics Letters 100, 133105 (2012); https://doi.org/10.1063/1.3697403

Macroscopic acoustoelectric charge transport in graphene
Applied Physics Letters 103, 133101 (2013); https://doi.org/10.1063/1.4822121
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.

The authors wish to express their deep gratitude to Dr. C. Y. Chang for his encouragement and stimulating discussions. We would also like to acknowledge the assistance of G. F. Chi in Materials Research Laboratory, Industrial Technology Research Institute, for technical assistance. This work was supported by the National Science Council, Republic of China under Contract No. NSC-75-0608-E006-05.


Interaction of surface acoustic waves with a two-dimensional electron system in a LiNbO₃-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 Bundesthet, D-6100 Darmstadt, Federal Republic of Germany

(Received 22 December 1987; accepted for publication 15 April 1988)

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 LiNbO₃ substrate. 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, 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 \( \leq \) 4.2 K) and in high magnetic fields (B \( \geq \) 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. 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 LiNbO₃ and the semiconductor heterostructure under investigation. The electric field of the SAW propagating on the LiNbO₃ delay-line decays on a length scale of about one SAW-wavelength into the substrate and the semiconductor located above it. 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 LiNbO₃
as the piezoelectric substrate have in the past been employed to study various acoustoelectric effects as convolution, measurements of the surface mobilities of different materials, acoustoelectric effects in superlattices and for the characterization of semiconductor properties. In the case of a 2DES under quantum conditions we have shown that the attenuation of a SAW passing the 2DES is given per unit length by

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

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. \( \sigma_{xx} \) is the magnetoconductivity of the 2DES and \( \sigma_m \) a characteristic conductivity where maximum attenuation occurs, given by

\[
\sigma_m = \sigma_0 (\epsilon_1 + \epsilon_2),
\]

where \( \sigma_0 \) is the Rayleigh velocity of the SAW and \( \epsilon_1, \epsilon_2 \) 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 \( \sigma_{xx} \) of the 2DES. 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 x 5 mm²) 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 \( \mu s \). 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 de-

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.
sired, 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 \( n_0 \) and mobilities \( \mu \). 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 magnetoresistance \( \sigma_{xx} \) drops to very low values which are lower than the conductivity \( \sigma_{xy} \). 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 \( n_0 \) 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.

We thank Christa Grabmaier from Siemens Forschungslabor for providing us with the LiNbO\(_3\) substrates. The financial support of the Deutsche Forschungsgemeinschaft is gratefully acknowledged.

---

**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 Associée au Centre National de la Recherche Scientifique 287, Université 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*

(Received 9 December 1987; accepted for publication 24 March 1988)

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\(_{0.49}\)In\(_{0.51}\)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-

---


