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**Fig. 1** LiNbO\(_3\) bulk-acoustic-wave transducer
\(\text{a Basic structure} \quad \text{b Practical structure of a relatively low-frequency transducer}

If we use ion-etching techniques, grooves with a depth of several micrometres or less would possibly be formed. Thus, it may not possible to obtain a transducer operating at very high frequencies, above several hundred megahertz. Moreover, this transducer is inherently of the nonresonant type, and therefore is expected to have wideband characteristics. Generally, both longitudinal and shear waves can be generated in this structure. The conversion efficiency depends on the surface orientation of the piezoelectric crystal, as well as on the exploitation parameters, \(w/\lambda\) and \(p/\lambda\). As in the case of conventional thickness-mode transducers, the 36°-rotated Y-cut is suitable for longitudinal-wave generation, and the X-cut and the 163°-rotated Y-cut for shear-wave generation.\(^{1}\) In the case of shear-wave transducers, it is desirable to align the grooves parallel to the displacement vector of the shear wave to be generated.

To examine how efficiently bulk waves can be generated in this structure, we fabricated relatively low-frequency transducers. The practical structure is shown schematically in Fig. 1b. The grooves were cut by means of a dicing saw. The electrodes were formed on the top surfaces of the ridges and the bottom face of the grooves by using photolithographic techniques, including a lift-off processing.

First, a shear-wave transducer was fabricated on X-cut LiNbO\(_3\). The grooves were aligned parallel to the displacement of the shear wave, which makes an angle of 37°-86°\(^{7}\) with the crystallographic Z-axis.\(^{2}\) The measurements were made by applying an RF pulse signal to the electrodes and observing the echo trains reflecting back from the opposite surface of the plate. The delay time between the echoes agreed well with that calculated from the shear-wave velocity. The conversion loss \(CL\) of the transducer was calculated from

\[ CL = \frac{1}{2} \log_{10} \left( \frac{V_t}{V_0} \right) \text{ dB} \]  

where \(V_t\) is the terminal voltage of the 50Ω source generator terminated with a 50Ω load resistance and \(V_t\) is the first echo amplitude when the transducer is directly connected to the source generator. The measured conversion loss characteristic is shown in Fig. 2, where \(N\) is the number of grooves and \(C_0\) is the clamped capacitance of the transducer. The frequency \(f_0\) where the depth of the grooves is equal to a half-wavelength is indicated in the Figure, along with the frequency \(f_m\) where the clamped impedance of the transducer becomes equal to 50Ω.

It is seen that the transducer has a large fractional bandwidth of about 110% and a conversion loss as low as 2.5 dB.

Next, we fabricated a longitudinal-wave transducer on 36°-rotated Y-cut LiNbO\(_3\), Fig. 3 shows the measured conversion loss characteristic. This longitudinal-wave transducer also exhibits a broadband characteristic, but the values of the conversion loss are somewhat higher than those of the shear-wave transducer. The cause of the dip seen at 37 MHz in Fig. 3 is not yet satisfactorily understood.

**Fig. 2** Conversion loss characteristic of shear-wave transducer using X-cut LiNbO\(_3\)

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**Fig. 3** Conversion loss characteristic of longitudinal-wave transducer using 36°-rotated Y-cut LiNbO\(_3\)

In conclusion, it has been demonstrated that the multigroove-structure BAW transducers have broadband and efficient conversion characteristics. If ion-etching techniques are used for fabrication of grooves, we may obtain BAW transducers for high frequencies up to several gigahertz. Using this type of BAW transducer, acousto-optic devices, in which LiNbO\(_3\) serves as both the piezoelectric medium for BAW generation and the acousto-optic medium, may be obtained.

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References

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**LOW-VOLTAGE MODULATOR AND SELF-BIASED SELF-ELECTRO-OPTIC-EFFECT DEVICE**

Indexing terms: Integrated optics, Optical modulators

We have demonstrated a quantum-well waveguide modulator with large (7:1) on-off ratio at low bias voltage (less than 0.5 V) compatible with high-speed electronics. The unique structure of this device permits bistable and other self-electro-optic-effect operations without an external power supply.
There has been much interest in quantum-well (QW) modulators for high-speed fibre-optical communication, as well as integrated optoelectronics. Optical modulators and optical bistable self-electro-optic-effect devices (SEEDs) have been demonstrated at 0.85 μm, both in normal incidence and in waveguide geometries. An optical modulator has been demonstrated near 1.5 μm, and also a low-voltage integrated laser/modulator device near 0.85 μm. It is important for these applications that the devices be compatible with the low drive voltages of high-speed electronics. We have demonstrated a QW waveguide modulator using the quantum-confined Stark effect (QCSE), which exhibits a large on/off ratio with less than 1 V drive voltage. The unique design of this structure also permits SEED operation without an external power supply. This has applications to integrated optoelectronics.

![Diagram](image1)

**Fig. 1** Sample structure

The superlattice consists of alternate 18 Å GaAs and 31 Å Al_{0.33}Ga_{0.67}As layers. The n- and p-doping levels are 10^{17} cm^{-3}, except for the top 1000 Å of GaAs, which is p-doped to 10^{19} cm^{-3}.

The device was grown by molecular beam epitaxy, lattice-matched to a GaAs substrate. The structure (Fig 1) was similar to that previously used. It consisted of two QWs embedded in a 3.7-μm-thick superlattice (SL) consisting of 19 Å GaAs wells and 31 Å Al_{0.33}Ga_{0.67}As barriers. The SL is then surrounded by GaAs cladding layers to form a leaky waveguide. As previously explained, the design of this structure is crucial to obtaining good contrast ratios. Although the leaky wavelength has nonzero insertion loss, in a real integrated optoelectronic device a conventional waveguide structure could be used, so insertion loss will not be a problem. The structure was PIN-doped to form a diode which could be reverse-biased to apply an electric field to the QWs. In contrast to the previous structure, the p and n regions are moved much closer to the QW region, giving the much thinner depletion region. The structure was cleaved to 150 μm in length and light from a dye laser was end-fired in to measure the absorption as described in Reference 3.

![Diagram](image2)

**Fig. 2** Absorption spectra of quantum-well modulator for incident polarisation (a) parallel to layers and (b) perpendicular to layers for applied voltages of (i) +0.75 V, (ii) 0 V, (iii) -0.75 V, and (iv) -1 V.

Positive voltage refers to forward bias.

Fig. 3 shows the relative transmission against voltage at 1.447 eV for the e, plane. A large on/off ratio of 7:1 is obtained with a forward bias of less than 1 V.

We have demonstrated optical bistability with this device without an external power supply. Here the device is used...


**VERY HIGH-TRANSDUCTION HETEROJUNCTION FIELD-EFFECT TRANSISTOR (HFET)**

*Indexing terms: Semiconductor devices and materials, Field-effect transistors*

A new form of FET has been demonstrated in the GaAs/AlGaAs material system. Designated the HFET, it has shown a transconductance of 500 mS/mm at 300 K for a nominal gate width, 2 μm, and a drain current of 430 mA/mm. The conduction occurs in an inversion channel at the heterointerface.

The sustained interest in heterojunction FETs over the last few years has been fuelled by the demand for a device structure fabricated in a high-mobility (and high-drift-velocity) material system and suitable as the basis for a VLSI technology. Most of the effort has focused on the HEMT1-4 (high-electron-mobility transistor), and many variations of the device have been investigated including normal and inverted structures, self-aligned and non-self-aligned devices and those that incorporate pseudomorphic strained layers to achieve higher channel mobilities. More recently the SISFET (semiconductor-insulator-semiconductor FET) has been investigated because of the way in which it closely emulates the MOSFET, the highly successful base of silicon VLSI technology.

![Physical cross-section of HFET](image)

**Fig. 1 Physical cross-section of HFET**

Although many of these structures hold promise in terms of individual device performance, it is still unclear that they can meet the requirements of uniformity and reproducibility that are necessary for a VLSI technology. In the search for alternative means to achieve a uniform and precisely controlled