IC COMPATIBLE SAW DEVICES ON GaAs

T. W. Grudkowski, G. K. Montress, M. Gilden and J. F. Black
United Technologies Research Center
Mail Stop #31
Silver Lane
East Hartford, CT 06108

ABSTRACT

The application of gallium arsenide (GaAs) technology to high frequency digital and microwave integrated circuits is rapidly maturing. The present work considers the additional capabilities afforded by the inherent piezoelectric properties of GaAs. The emphasis of the work is on Surface Acoustic Wave (SAW) device configurations which may eventually be integrated with electronic circuits on the same substrate. The basic transduction and propagation characteristics for Rayleigh waves on <001>, (110) GaAs are reviewed for device operation in the 100-200 MHz frequency range. Recent developments in the design and performance of tunable SAW phase shifters, two-port SAW resonators having loaded Q's up to 13,000, and a monolithic asynchronous correlator/programmable matched filter are presented. The potential of the technology for further development is also addressed.

Introduction

Recent developments in GaAs technology have demonstrated its potential for increasing the speed and frequency of digital and microwave integrated circuits. While the advantages of a higher electron mobility and a larger bandgap for GaAs relative to silicon have led to these developments, the piezoelectric properties of GaAs may also be exploited to broaden the circuit design options available.[1] In this paper we summarize progress in the development of Surface Acoustic Wave (SAW) devices fabricated on semi-insulating and epitaxial GaAs substrates. These devices include continuously variable phase shifters, resonator filters having loaded Q's as large as 13,000 at 118 MHz, and programmable correlators for processing spread spectrum waveforms at 10 MHz chip rates. Since the GaAs substrate material and orientation are identical to that used for GaAs IC development, the SAW and electronic circuits can be fabricated on the same substrate to form a monolithic subsystem.

SAW Properties and Transduction Techniques

Surface wave propagation along a (110) or equivalent direction on a <001> oriented substrate is used for this work because this is the preferred substrate orientation for GaAs IC development and also because it provides the largest available piezoelectric coupling coefficient, $\Delta V/V = 0.00036$. This piezoelectric coupling coefficient is only about 38 percent less than that found for ST-X quartz, which is a commonly used temperature compensated SAW substrate having a zero linear temperature coefficient of delay (TCD) at room temperature (25°C). While GaAs is not a temperature compensated SAW substrate, the use of thin film overlays has provided a means for achieving a zero linear TCD.[2] Uncompensated, the temperature coefficient of delay for GaAs is approximately +52 ppm/°C. Electronic temperature compensation methods may also be used. The SAW velocity of 2886 m/sec for GaAs is also comparable to the SAW velocity of 3158 m/sec for ST-X quartz.

This work was partially supported by Rome Air Development Center, Air Force Systems Command under Contract F19628-79-C-0056 and by USAERADCOM, Ft. Monmouth, NJ, under Contract DAAK20-79-C-0263.

Interdigital transducers on semi-insulating GaAs make use of the piezoelectric coupling available and can be designed using standard methods by treating the substrate as an insulator. However, when using semiconducting material, the mobile charge carriers short out the piezoelectric fields of the wave and also the exciting fields of the transducer. To circumvent these problems, the transducer electrodes are fabricated as Schottky barriers. With a dc reverse bias applied the mobile charge carriers can be depleted so that the transducer operates just as if it were on the equivalent semi-insulating substrate. The bias voltage required for complete depletion of the epitaxial layer depends upon its doping level and thickness.

Where fractional bandwidths exceeding about 5 percent with moderate conversion loss are required, ZnO overlay transducers may be used.[3] If even greater bandwidths are required, alternate designs such as edge-bonded transducer are available, although with a sacrifice in ease of fabrication.[4] Such techniques hold promise for achieving octave bandwidths with good conversion efficiency.

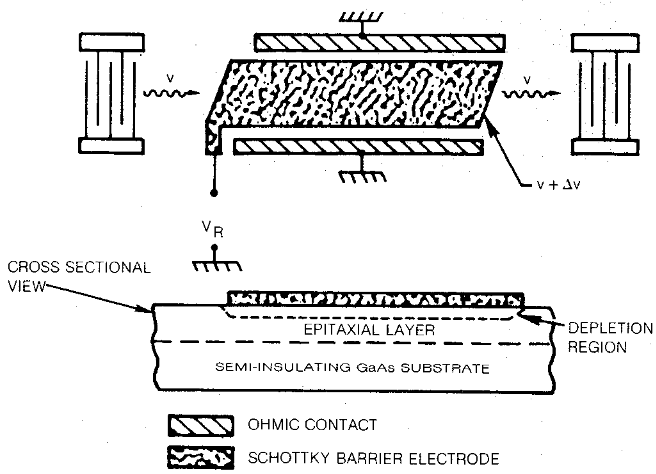

Fig. 1 GaAs SAW Phase Shifter

SAW Phase Shifter

The SAW velocity, or phase shift between two transducers may be electronically varied by applying a reverse dc bias voltage to an intermediate Schottky barrier electrode configured as shown in Figure 1.

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As the depletion depth is increased with increasing reverse bias, the SAW electric fields within the bulk are gradually restored, and the velocity or phase delay altered. Eventually an effective insulating condition is reached.

The change in SAW velocity versus reverse bias voltage produced with an experimental SAW phase shifter is shown in Figure 2. The epitaxial layer thickness and carrier concentration were 4 µm and $n = 10^{15} cm^{-3}$, respectively. The maximum velocity change observed, approximately 575 ppm, corresponds to an electronically adjustable phase shift of 85 degrees at 118 MHz. For operation at 200 MHz, a 90 degree phase shift control range could be achieved for a 0.65 cm long propagation path length. Throughout the voltage tuning range, the variation in SAW propagation loss was less than 0.5 dB for a 1 cm long electrode. The dc power drain of the phase shifter is extremely low because of the reverse biased operation of the Schottky barrier electrode.

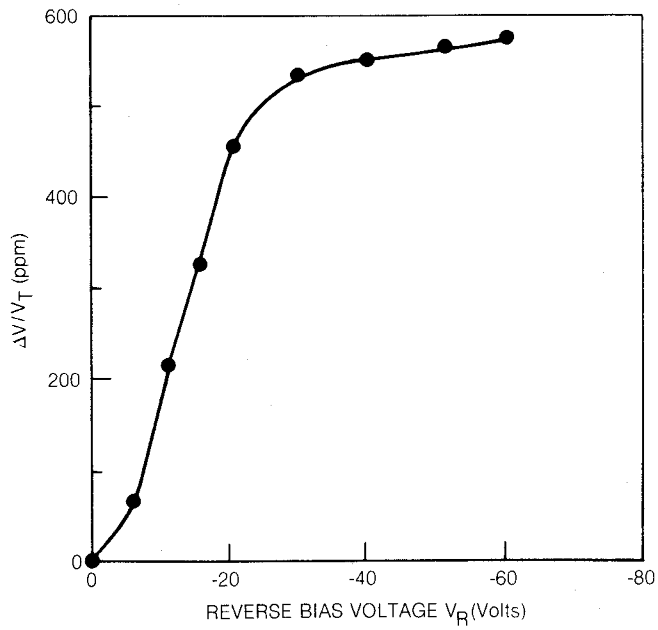

Fig. 2 GaAs SAW Phase Shifter Performance

Two-Port Resonators

The ability to realize high Q resonators on GaAs has potential impact on the fabrication of stable oscillators in monolithic form. Two-port resonators have been fabricated, initially on semi-insulating GaAs, using metallic strip gratings as shown in Figure 3a. The metallic strip gratings, when fabricated as Schottky barriers on epitaxial material, are also of interest for the construction of voltage tunable resonators. The maximum loaded Q values achieved in air, as measured untuned in a 50 Ohm measuring system, were 11,500 at 179 MHz and 13,000 at 118 MHz. Resonators having ion-milled groove reflectors have also been fabricated with comparable results. While the optimum design iterations have not as yet been experimentally implemented, the results achieved indicate that the material is capable of supporting high Q's, comparable to those for quartz at a similar state of development.

Figure 3b shows the measured insertion loss characteristic for an aluminum strip grating resonator with 500 reflector elements. The fabrication process for these resonators included lift-off photolithography in defining the metal patterns. Metallization thickness was approximately 800 Å of Cr/Aℓ.

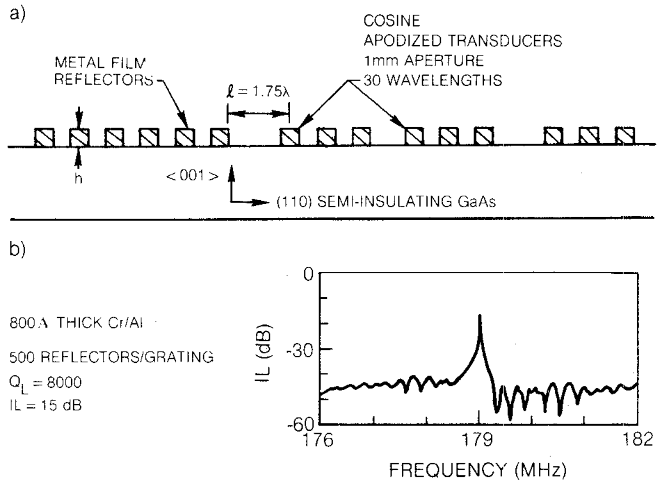

Fig. 3 Metallic Grating Resonator Design and Characteristic

Monolithic Signal Processors

SAW signal processing structures can also be fabricated on GaAs to perform high speed convolution, correlation, and Fourier analysis. The advantages of SAW technology include large processing bandwidth and high processing speed. While numerous SAW materials and device configurations have been reported,[5] the GaAs SAW signal processors under development are extremely competitive in their performance and are suitable for monolithic subsystem integration. One programmable correlator configuration, capable of processing PSK coded signals at 10 MHz chip rate, is shown schematically in Figure 4.

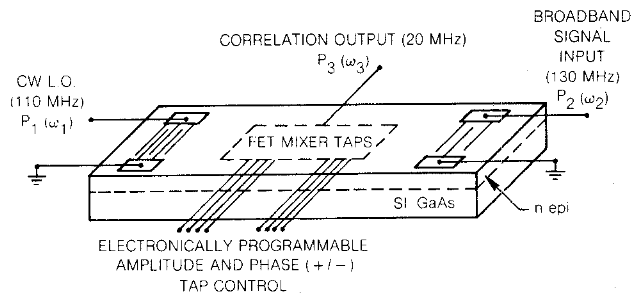

Fig. 4 Nondegenerate Asynchronous GaAs Correlator Design

A PSK coded input signal at carrier frequency f_2 is launched at one end of the delay line and interacts with a cw local oscillator wave at frequency f_1 within the central FET-tapped interaction region. Correlation is achieved between the PSK coded input signal and the spatial tap code, as electronically programmed through the applied dc bias at each tap. Because the reference code is electronically fixed at the taps, the device performs as an asynchronous matched filter, with the correlation output at $f_3 = f_2 \pm f_1$ achieved independent of signal timing and with its time scale unaltered. The input wave at f_1 thus serves only to provide a local oscillator for the mixing process and can be launched by a narrow bandwidth transducer. The advantages of using a mixing process, rather than a single frequency tapped delay line structure, include the large tap amplitude control range and biphase tap output control provided within the FET SAW mixer, and the compensation for acoustic propagation loss through the use of counterpropagating input and local oscillator waves. With the correlation output obtained at a frequency other than the input frequencies or their harmonics, bandpass filtering at the output port eliminates spurious contributions due to direct electromagnetic feedthrough.

The FET tap configuration, shown in Figure 5, consists of segmented Schottky barrier gate and ohmic drain contacts and a common ohmic source electrode. The FET periodicity is also consistent with the desired PSK code chip rate, which is equal to the tap sampling frequency, f_s. Direct control of the amplitude as well as phase (+/-) of the mixer output is achieved by electronic control of the magnitude and polarity of the FET dc bias. The mW level power dissipation per tap, 65 dB input dynamic range, 55 dB tap amplitude control range and 50 dB spurious levels which have been measured represent state-of-the-art performance for a tap-programmable correlator. The monolithic configuration, using n/semi-insulating GaAs is also compatible with further integration of peripheral electronics.

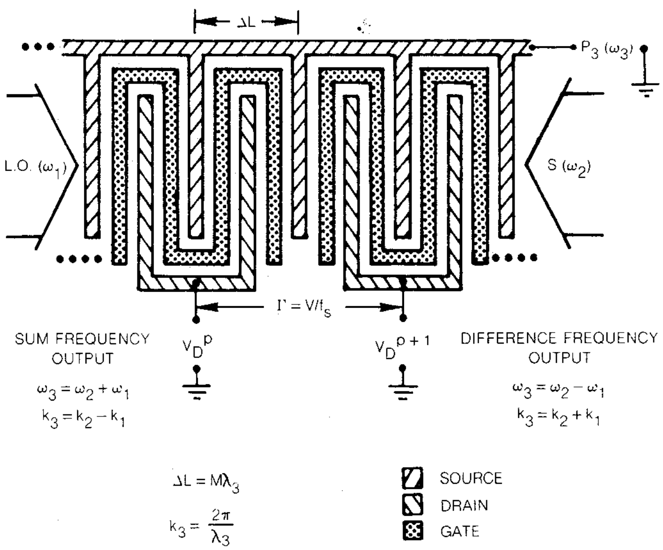

Fig. 5 FET Tap Structure

The correlation response for a 31 chip PSK pseudo-random M sequence with a 10 MHz chip rate is shown in Figure 6. The sidelobe distribution is close to the theoretical response for this sequence with a 14 dB peak to maximum sidelobe level as compared to the ideal 15.8 dB level expected for the code used.

The experimental correlator had 32 taps with equal linewidths and spacings for the source, gate and drain electrodes and an intertap spacing, Γ, of 286.7 μm corresponding to a 10 MHz code chip rate. The epitaxial layer had a carrier concentration of $n = 10^{16}$ cm^{-3} and a layer thickness of 1.3 μm. Both transducers were of the reverse biased Schottky barrier type, with 12.5 and 25 wavelengths for the transducers at f_2 and f_1, respectively.

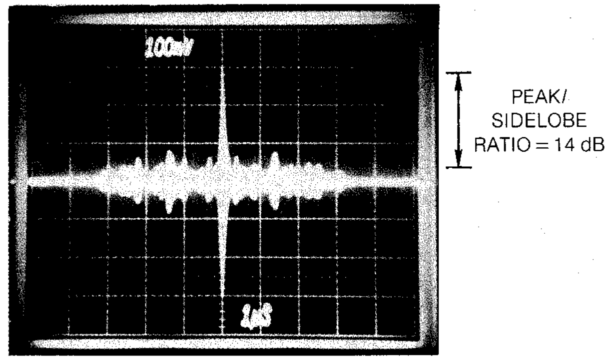

Fig. 6 GaAs Correlator Output

Conclusions

The results achieved for monolithic GaAs SAW devices are quite encouraging and show considerable promise for improvement. Device configurations have been pursued using the same type of fabrication processes and materials which are currently being developed for GaAs IC electronics. When moderate bandwidths are needed, only two photomask steps are required for device fabrication and the need for special transducer techniques is eliminated, thus easing fabrication complexity and improving yield. If required, broad bandwidth transducer methods are possible, using ZnO or edge-bonded structures.

Acknowledgements

The authors are indebted to B. Bujnarowski, M. Branciforte and C. Gerstung for device fabrication; to L. Hughes and A. Vincent for epitaxial growth; and to R. Rukus and S. Sheades for device testing. The authors also acknowledge the skilled typing of N. Michels and B. Surprenant in preparing the manuscript.

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