

Development of GaAs-Based Monolithic Surface Acoustic Wave Devices for Chemical Sensing and RF Filter Applications

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Introduction

Since their invention in the mid-1960's, surface acoustic wave (SAW) devices have become popular for a wide variety of applications. SAW devices represent a low-cost and compact method of achieving a variety of electronic signal processing functions at high frequencies, such as RF filters for TV or mobile wireless communications [1]. SAW devices also provide a convenient platform in chemical sensing applications, achieving extremely high sensitivity to vapor phase analytes in part-per-billion concentrations [2]. Although the SAW acoustic mode can be created on virtually any crystalline substrate, the development of SAW technology has historically focused on the use of piezoelectric materials, such as various orientations of either quartz or lithium niobate, allowing the devices to be fabricated simply and inexpensively. However, the III-V compound semiconductors, and GaAs in particular, are also piezoelectric as a result of their partially covalent bonding and support the SAW acoustic mode, allowing for the convenient fabrication of SAW devices. In addition, GaAs microelectronics has, in the past decade, matured commercially in numerous RF wireless technologies. In fact, GaAs was recognized long ago as a potential candidate for the monolithic integration of SAW devices with microelectronics, to achieve compact RF signal processing functions [3]. The details of design and fabrication of SAW devices can be found in a variety of references [1].

GaAs SAW Devices

A typical SAW device, for applications such as chemical microsensors or RF filters, is in the form of a two-port delay line. In a two-port delay line configuration, two metal film interdigital

transducers (IDTs) are defined on the substrate using appropriate lithography techniques. One IDT is used to create the acoustic wave, the other to receive it. A RF voltage applied across the transmitter creates a surface atomic displacement using the piezoelectric properties of the substrate, and launches the SAW acoustic mode. After some delay time, depending upon the physical separation between the transducers and the acoustic velocity of the substrate, the receiver transduces the acoustic wave back to an electrical signal. Some important material properties for GaAs SAW devices are shown in Table 1, compared to the same properties for some typically used orientations of both quartz and lithium niobate.

	Velocity (m/sec)	K ² (%)	TCD ppm/C
LiNbO ₃	3480	4.5	80
ST-quartz	3160	0.11	0
GaAs (001)	2860	0.07	50

Table 1. Several material properties relevant to fabrication and performance SAW devices.

Although GaAs is very attractive as a substrate for the monolithic integration of acoustic devices and RF microelectronics, the widespread use of GaAs SAW devices has been at least somewhat limited by the physical properties of the GaAs (001) orientation shown in Table 1. First of all, the acoustic velocity of the substrate and the desired frequency of operation determine the wavelength of an IDT. For example, in a typical 2.4 GHz wireless filter application, the wavelength of a GaAs SAW device would be about 1.2 μ m. Because many IDT designs utilize a quarter-wavelength finger spacing, the critical dimension of the fingers within the transducer would be about 0.3

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μm. Such small feature sizes are achievable only by electron beam lithography or state-of-the-art photolithography methods. From lithography considerations alone, therefore, the faster acoustic velocities of both ST-quartz and lithium niobate are advantageous in high frequency SAW device applications. Furthermore, the conversion efficiency of the IDT is measured by the electromechanical coupling coefficient (K^2), as a percentage of acoustic displacement with applied voltage. GaAs (001) has an electromechanical coupling coefficient of similar magnitude to the commonly used ST-quartz SAW substrate, but is somewhat less, resulting in slightly higher insertion losses for GaAs SAW devices. The IDT must be oriented for optimized acoustic coupling, producing an acoustic wave parallel to a [110] surface direction of the GaAs (001) substrate. Finally, the GaAs (001) substrate has a temperature coefficient of delay (TCD) of about 50 ppm/C near room temperature. The TCD increases the acoustic velocity with decreasing temperature, producing corresponding changes in acoustic delay time and wavelength shift within the IDT. The TCD can be a serious issue for high-precision SAW filters, but may be only a minor inconvenience in other applications where temperature effects can be either tolerated or compensated electronically.

Monolithic Integration

The monolithic integration of GaAs SAW devices and microelectronics has recently been achieved. The work discussed here focuses on the development of integrated vapor-phase chemical microsensors based on SAW devices. In a chemical sensing application, the SAW device is used to absorb an analyte of interest, typically in a polymeric coating applied to the delay path of a two-port SAW delay line [2]. The absorbed mass *reduces* the acoustic velocity, resulting in an *increased* signal transit time through the SAW device. In practice, the SAW device is placed in the feedback loop of a RF oscillator, and changes in the delay time with absorbed mass result in a shift in the output frequency of the oscillator. Typical

delay times for a GaAs SAW sensor are about 0.5 μsec, providing a large enough surface area to achieve adequate chemical sensitivity. A practical sensor would have an array of several SAW delay lines, each coated with polymeric materials optimized to absorb or reject specific analyte species [2].

A microphotograph of a monolithic GaAs SAW oscillator is shown in Figure 1 and a detailed schematic diagram is shown in Figure 2. The oscillator consists of two integrated components, a four-stage GaAs MESFET amplifier and a GaAs two-port SAW delay line. The output signal from the amplifier is used as feedback, through the SAW device, into the input stage of the amplifier to form the oscillator circuit. The SAW device, therefore, controls the operating frequency of the oscillator. Each stage of the amplifier is designed to achieve about 10 dB gain to overcome the insertion loss of the GaAs SAW device.

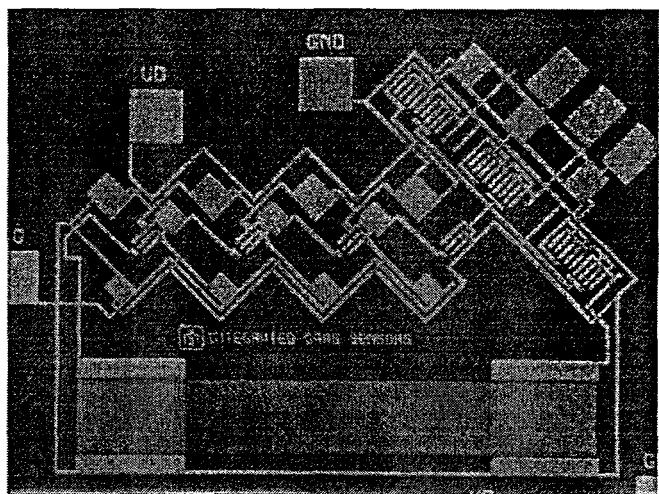


Figure 1. A microphotograph of a monolithic integrated GaAs SAW oscillator. The area of view is approximately 1.9 x 1.2 mm.

The SAW device shown in Figure 1 has a wavelength of 6 μm and a transducer separation of 1140 μm. The transmitting IDT (right most) and receiving IDT (left most) each contain 50 finger pairs. The fabrication of the monolithic SAW oscillator was achieved with the addition of a single transducer metallization layer to a standard GaAs

MESFET fabrication process. Details of the device fabrication process can be found in reference [4]. An output frequency spectrum from the integrated GaAs SAW oscillator is shown in Figure 3. The oscillator operates at about 471.8 MHz with a FWHM of about 20 kHz and a power consumption of 50-60 mW at 3 VDC. Similar oscillators, operating at 200 MHz and 350 MHz, were also operational.

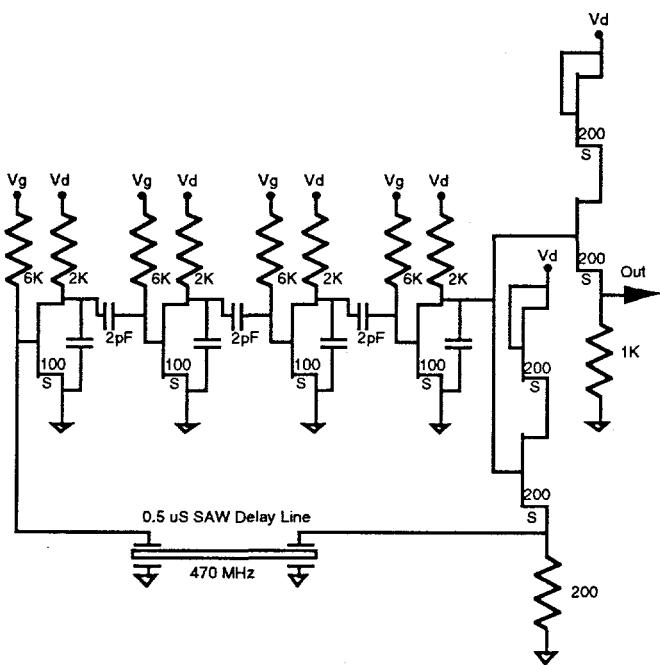


Figure 2. Schematic diagram of the monolithic GaAs SAW oscillator shown in figure 1.

Future work

The development of monolithic integrated GaAs SAW devices as chemical microsensors is ongoing. Future versions of the GaAs SAW oscillator are expected to employ GaAs HBT transistor technology for improved low-noise operation in addition to integrated impedance matching components for reduced overall circuit power consumption at higher frequencies. Various applications for SAW RF filters will also be investigated along with increased levels of on-chip electronic signal processing capability.

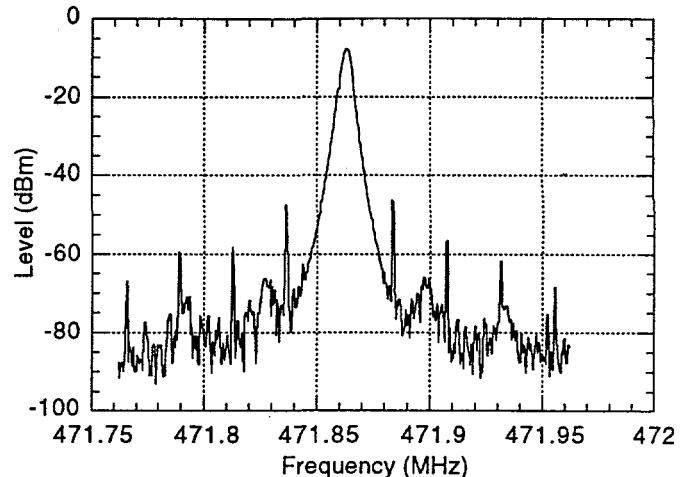


Figure 3. The frequency spectrum of the GaAs SAW oscillator shown in Figure 1, operating at 471.86 MHz.

References

- [1] See, for example, Colin K. Campbell, *Surface Acoustic Wave Devices for Mobile and Wireless Communication*, Academic Press, San Diego, 1998, and numerous references therein.
- [2] D.S. Ballantine, R.M. White, S.J. Martin, A.J. Ricco, E.T. Zellers, G.C. Frye, and H. Wohltjen, *Acoustic Wave Sensors Theory, Design, and Physico-Chemical Applications*, Academic Press, San Diego, 1997.
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