Micromachining Concept on GaAs and a mm-Wave Oscillator Example

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Micromachining can place cavities, slots, microstrip lines. air gaps and other mechanical structures directly onto the semiconductor substrate material

Present technology demands reduced manufacturing cost, size, weight and improved performance for wireless and location services exploitation like GPS, as well as for the millimeter wave devices. This kind of demand for wider bandwidth along with state-of-the-art performance can be accomplished with the use of micromachining and MEMS technology [1]. Developing micromachined technology is also essential for the future of integrating the entire communication system on a single chip.

Presently, the demand is for the development of components and devices in ever-higher frequency bands. At higher frequencies realization of circuits using planar technology results in modal dispersion along with the decrease in the phase velocity. Also at high frequency, loss—whose dependency is cubic with the frequency—creates limitations in the successful realization of the circuits. To overcome these limitations either the substrate has to be shrunk or a substrate-free propagation structure has to be built. Micromachining is currently the most suitable method for substrate free propagation. And the potential to enable wide operational bandwidth, eliminate off-chip passive components, make interconnect losses negligible, and have process compatibility with the existing MMIC process are added advantages. Both GaAs and Si offer a wide range of possibilities in this area. High resistivity Si has been considered to be the most suitable candidate due to ease of etching, well defined processes and planes for etching. But it is incompatible with the existing GaAs-based MMIC technology.

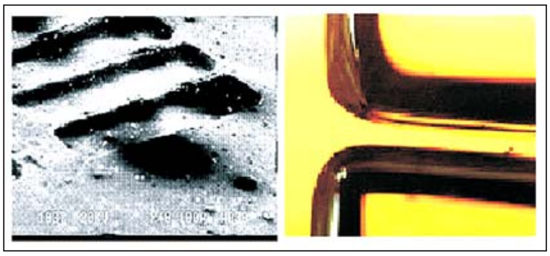

Figure 1 · Micromachining examples on GaAs wafer.

For compatibility with existing MMIC-based circuits, mostly on GaAs, the process has to be well defined for micromachining on GaAs. As pHEMT and mHEMT up to 0.15 µm have matured enough compared to SiGe HBTs, the circuits based on GaAs have far more potential at millimeter wave frequencies. Designing components on GaAs substrates offers the possibility of a full monolithic system integrated with the active circuits built by MMIC technology. In this paper the focus will be on the machining aspect of the GaAs, its realization and further potential, and its application for an integrated reliable source at millimeter frequencies.

Fabrication Steps on GaAs

Fabrication of MEMS/micromachining devices are carried out mainly by four techniques—bulk micromachining, surface micromachining, LIGA and SCREAM. For dispersionless and substrate mode free propagation, bulk micromachining is easier in realizing high frequency circuits. In bulk micromachining, the 3-D structure is supplied within the confines of a wafer by exploiting the anisotrop-

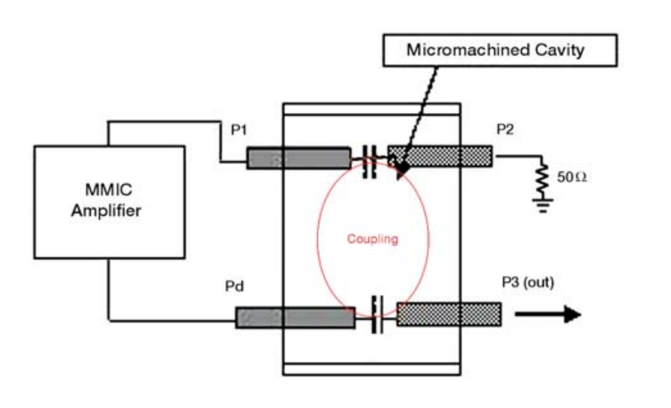

Figure 2 · Concept of slot coupling in GaAs wafer.

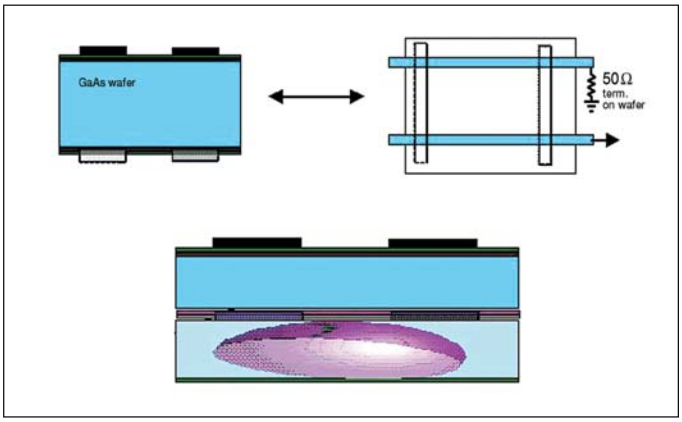

Figure 3 · Wafer stacking process.

ic etching rates of different atomic crystallographic planes in the wafer. The front-end processing consists of dielectric and metal deposition. This consists of deposition of Si_3N_4 of .10-.12 µm followed by polyimide using PECVD and post baking with an additional thickness of 1.1-1.2 µm. Use of polyimide increases the average power handling capability. The thermal resistance of polyimide is about 200 times the thermal resistance of GaAs. Back side etching consists of opening at the back side using wet etchants $H_2SO_4/H_2O_2/H_2O$ and using photo resist as a mask. The etching of GaAs is highly anisotropic and tilt is pronounced at the (011) section [2]. Metallization of the pattern has to be carried out using a lift off process. For the indigenous process of micromachining, a double sided low resistivity wafer of 650 µm has to be used. In this case, it was thinned down to 200 µm. The inhouse micromachining on GaAs was aimed to etch out nearly 100 µm from the wafer of 200 µm. The criticality is the profile and the etch rate which has to be precisely controlled. The inhouse processing steps for the back side etching are:

Structure	Q
Rectangular Wave guide (nonplanar)	8000
Slot resonator over cavity	500
Microstrip over membrane	234
Microstrip over Si	125
DR	>10,000

Table 1 · A comparison of Q obtained using various structures.

1. Preparation of the GaAs wafer for the resist coating using electron beam resist.
2. Post baking the resist and writing on it using electron beam lithography.
3. De-scum of the wafer so that residues are removed and ready for the etching.
4. Wet etching while controlling the etch rate and undercut.
5. Depth measurement using optical microscope.

The samples show the depth of 100 µm achieved as per the requirement after four samples run on the wafer. Figure 1 shows the machined cavities on the GaAs wafer of the dimensions 2400 µm × 400 µm with the gap of 300 µm. The depth was decided to be kept around 100 µm.

Advantages of Machined Lines

Both micromachined microstrip lines and micromachined CPW lines have been exploited for high frequency circuit realization. Access to both signal and ground planes on the same plane, removal of via holes and high power handling capability, makes the conductor backed CPW lines most versatile and easy to use among micromachined lines. The micromachined line reduces the propagation losses, frequency dispersion and non-TEM modes. Membrane supported lines such as microstrip lines, shielded membrane microstrip lines, microshield lines and shielded strip lines. External high Q resonator can be replaced using micromachined lines equivalent to air dielectric line with wide transverse dimensions, resulting in high Q at millimeter wave frequencies as well as increased average and peak power handling. It has been found out that the Q of the micromachined line excited in WGM mode is comparable to the metallic cavity as shown in Table 1 [3,4]. This knowhow can be most suitable for filter and oscillator applications, where the effect of Q is more pronounced in the insertion loss and phase noise to a great extent. This article concentrates on the realization of a micromachined oscillator. The structures, after careful study, have been simulated, then implemented practically for evaluation. The various forms of Q are related according to the following equations:

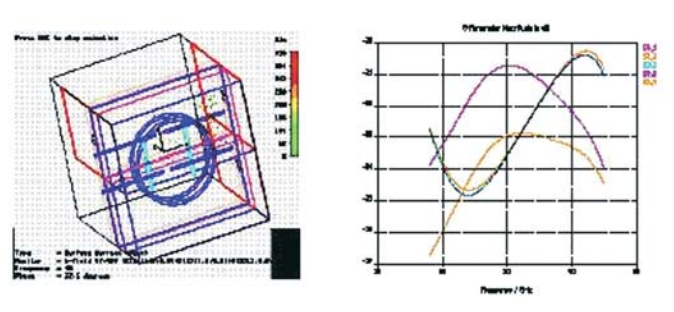

Figure 5 · Simulated responses along with the simulated structure.

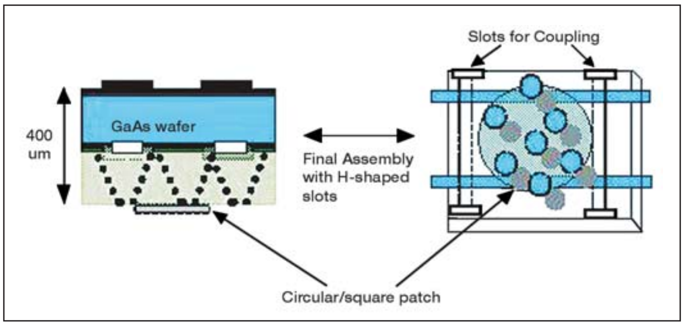

Figure 6 · Active antenna design using slot coupling to the GaAs wafer.

$$Q_L^{-1} = Q_U^{-1} + Q_E^{-1}$$

$$Q_{loaded} = f_0/\Delta f,$$

$$Q_{ext} = 10^{-([S21(dB)/20])} \cdot Q_{loaded}$$

The comparison summary of Table 1 shows that the Q of the dielectric puck is highest but at high frequency the size of the puck, along with the required position accuracy, makes it unsuitable for realizing a relaible oscillator. The use of WGM mode gives Q factor of around 5000, which is ideal for realizing planar circuits.

Simulated Structures

The aim of the simulated structures is to show the capability of creating a highly stable source using the micromachined concept on the GaAs wafer. CST (Computer Simulation Technology) software has been extensively used for the passive circuits' simulations. Figure 2 shows the concept of slot coupling where the magnetic field is used to couple through the slot [5]. The second machined wafer is stacked on the first one using epoxy (Fig. 3). This will in turn give a high *Q* resonator. Further modification to this is the concept of capacitive loading the lines using a gap, which the authors believe enhances the *Q* where gap can be optimized. This concept is shown in Figure 4, along with the first cut simulated results. The transmission losses have to be further reduced through optimization (Fig. 5).

A novel concept of an active antenna along with the resonator has been tried out (Fig. 6). Here the slot coupling will be from the H-shaped slot [8]. Instead of machining, closely-spaced vias on the second wafer will be etched. On the other side, a patch either in circular or rectangular shape can be patterned. The coupled energy through the slot to the patch makes it radiate. This becomes a radiating antenna along with the oscillator. The concept is demonstrated in Figure 7.

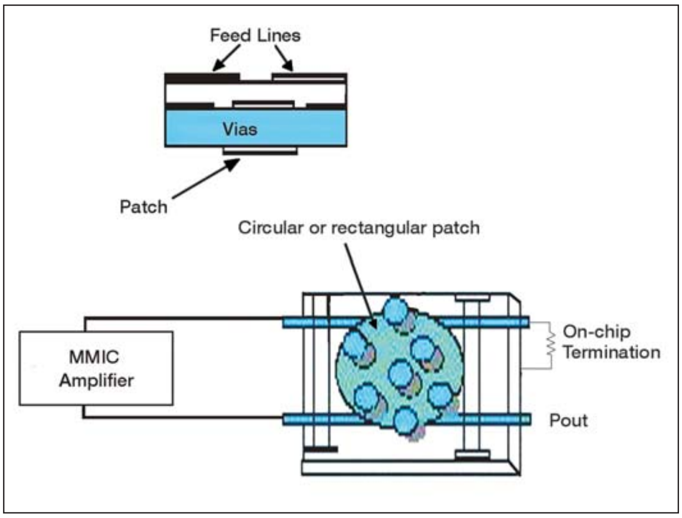

Figure 7 · Combination of the active antenna and oscillator.

Conclusion

Micromachining of the GaAs wafer has been done successfully with the simple steps described in this paper. Several aspects of machining to obtain circuit realization at high frequency have been shown. Stability and compatibility issues concerning a highly stable source can be eliminated with the use of machining. Machining on GaAs can open a new era for realizing reliable and cheaper active circuits for space and defense applications.

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