

INP HBT ON SI SUBSTRATES WITH INTEGRAL PASSIVE COMPONENTS: A WAFER SCALE PACKAGE

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Abstract

An InP-based HBT is integrated to a Si substrate insulated with BCB by removing the InP substrate and bonding the active device layers. The DC and RF characteristics show minimal degradation after bonding to the Si. Transmission line structures are fabricated and measured on both bare Si and Si coated with BCB. Insertion loss of the CPW lines demonstrate useful high frequency propagation with BCB on the lossy substrate. Utilizing these results, an amplifier is designed to demonstrate InP thin-film integrated high frequency circuits on silicon. These results point to the development of wafer scale packaged high frequency electronics.

Introduction

The rapidly emerging market for microwave wireless applications requires low-cost integrated components. InP and GaAs components offer superior high frequency performance to their Si counterparts but are not as competitive when considering cost and integration. Combining the benefits of high performance III-V semiconductor devices and circuits with low cost silicon substrates can reduce cost and improve functionality.

The technique of thin film integration has recently gained new interest for directly combining compound semiconductor electronics with Si based systems [1-9]. Thin film integration, illustrated in Figure 1, provides a near monolithic method of integrating the two material systems without adding parasitics associated with hybrid methods. In addition, conventional microelectronic processing can be used for low-loss interconnects.

Typical silicon substrates are lossy and therefore high frequency signals propagate poorly through signal lines fabricated on silicon. High resistivity (HR) silicon

substrates have been shown to be an acceptable microwave substrate [10-12], but are more expensive than conventional Si substrates and are not completely compatible with Si VLSI processes. Use of low loss dielectric material, such as BCB, spun onto silicon has been used in demonstration of microstrip components on lossy materials [13-17].

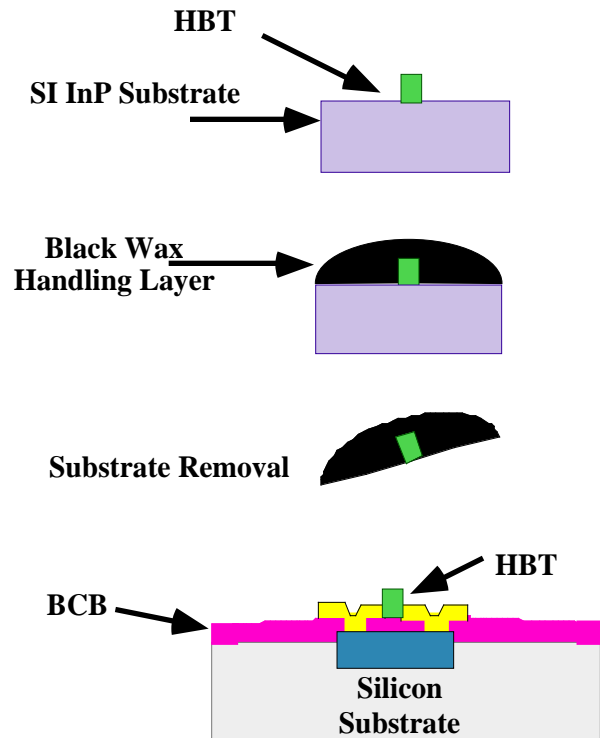


Figure 1 Diagram illustrating thin film integration. 1) Device fabrication, 2) Handling layer applied, 3) Substrate removed, 4) Bond to host substrate

There are two issues that must be addressed for thin film integration of III-V components to be

successful: the thin film integration process should preserve the high frequency performance of the active components, and the characteristics of the transmission lines and passive components on silicon must be comparable to similar microwave components on semi-insulating (SI) substrates.

This paper will demonstrate the first integration of InP thin film high frequency components onto Si. Results show preservation of the high frequency response of an InP based heterojunction bipolar transistor (HBT). A comparison of the loss characteristics of coplanar waveguide (CPW) transmission lines on various Si wafers with and without a layer of BCB is also presented. Using these results, a high frequency integrated circuit is designed and simulated on a Si substrate using CPW matching networks.

Technique

In preparation for substrate removal, the HBT samples were covered with an Apiezon W handling layer which also serves to protect the devices from the substrate removal etch. The samples were then placed in hydrochloric acid which selectively etches the InP substrate, leaving only the active layers of the device. After the substrate was fully removed, the samples were rinsed in DI water, and then transferred to the new host substrate. Pressure was applied to the sample to contact bond it to the host substrate. After the sample was thoroughly dry, the Apiezon W was dissolved in trichloroethylene. Ti and Au were then evaporated onto the host substrate and co-planar structures were patterned using conventional post-processing techniques.

Experiment and Results

Table 1 describes the various host substrates and the different dielectric layers used in this investigation.

Table 1 Host Substrate

Name	Material	Resistivity	Dielectric Layers
S1	Si	.375-.625 Ω cm	15 μ m BCB
S2	Si	500-1000 Ω cm	15 μ m BCB
S3	Si	0.01-0.02 Ω cm	0.5 μ m Si_3N_4 15 μ m BCB
S4	Si	.375-.625 Ω cm	7 μ m BCB

The S-parameters and I-V curves of the InP HBT before and after thin film integration were measured with a

HP8510C network analyzer, HP4145 semiconductor parameter analyzer, and a Cascade on-wafer probe station. The measured DC performance and S-parameters shown in Figures 2 and 3 respectively show only a slight deviation from the on-wafer results. In Figures 4 and 5, the figures of merit f_t and f_{max} of the HBT before and after removal of the substrate are comparable. Upon comparison of the DC and RF response at the same collector current, there is a change in the behavior of the transistor as shown in Figures 6 and 7. The change may be attributed to the bonded interface or to fact that the devices are only 1 μ m thick. Modeling of the thin film HBTs are in progress and conclusions on the cause of change in characteristics will be presented at a later date.

Successful high frequency signal transmission requires isolation of the passive components from the lossy substrate. To insulate the passive elements from the lossy Si substrate, a 15 μ m layer of benzocyclobutene (BCB) is spun on the wafers. In this study, CPW transmission lines are fabricated on Si wafers with and without BCB to compare the loss on the different substrates. Figure 8 shows the loss characteristics of transmission lines, 84 μ m wide signal line and 50 μ m spacing, fabricated on various substrates. At 10 GHz, an acceptable loss of less than 4 dB/cm is exhibited by three of the substrates. Although these results are higher than the 2 dB/cm loss reported from similar experiments with microstrip structures [13], they are of comparable loss. The lack of a backside ground plane in the CPW transmission line structures used in this investigation allows field penetration into the lossy silicon substrates, which accounts for the higher loss.

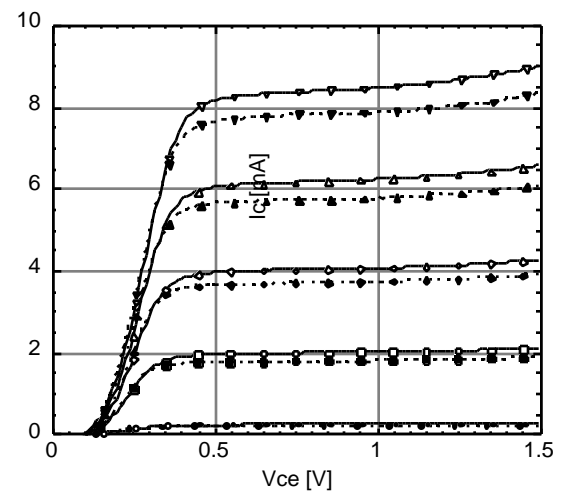


Figure 2 I-V characteristics of HBT on-wafer (solid line) and bonded to BCB on Si (dashed line).

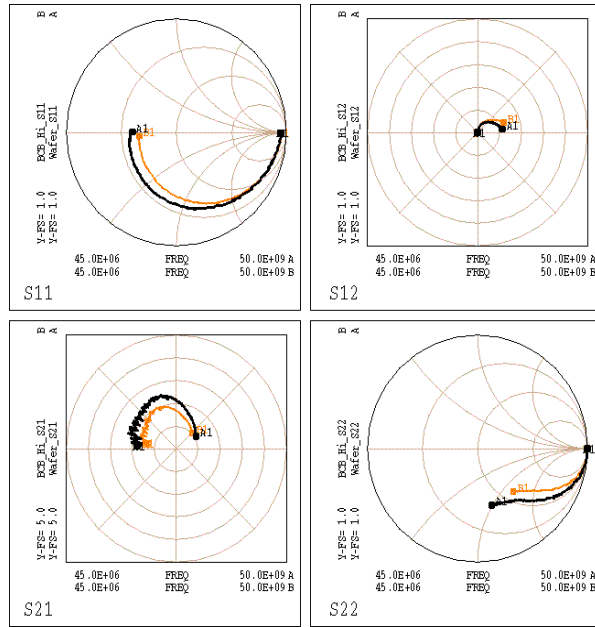


Figure 3 Comparison of S-parameters of HBT on-wafer (dark line) and HBT on BCB insulated Si substrate (gray line).

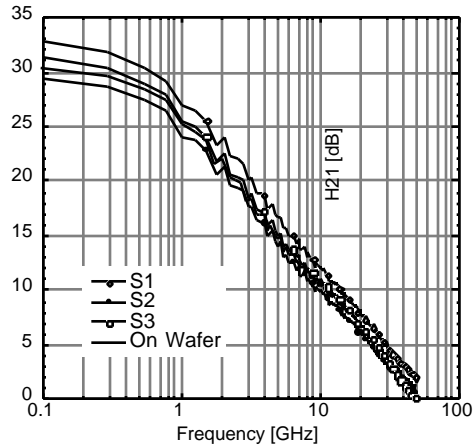


Figure 4 H_{21} of HBT at $V_{ce}=1.5V$ $I_c=2mA$ on various substrates.

Using these results, a matched amplifier utilizing BCB/Si CPW matching networks integrated with a thin-film InP HBT has been designed, see Figure 9.

In summary, the results presented represent the first example of thin film integration of InP high frequency components onto a Si packaging substrate. We demonstrate the feasibility of the direct packaging of millimeter-wave components with Si substrates and the development of millimeter-wave InP/Si integrated circuits.

Future progress will help develop the concept of wafer scale packaging for millimeter-wave electronics.

Acknowledgments

NSF Packaging Research Center at Georgia Tech in contract EEC-940273, NSF Career Award and Army Young Investigator Award.

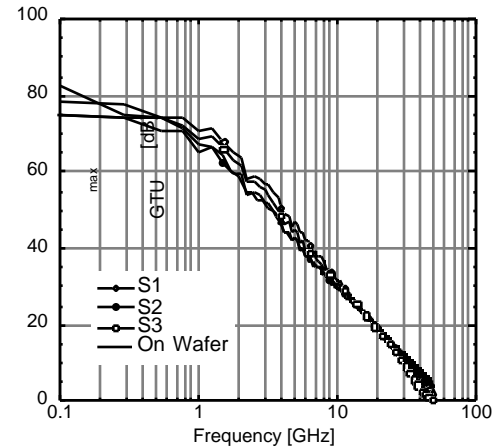


Figure 5 GTUmax of HBT at $V_{ce}=1.5V$ and $I_c=2mA$ on various substrates.

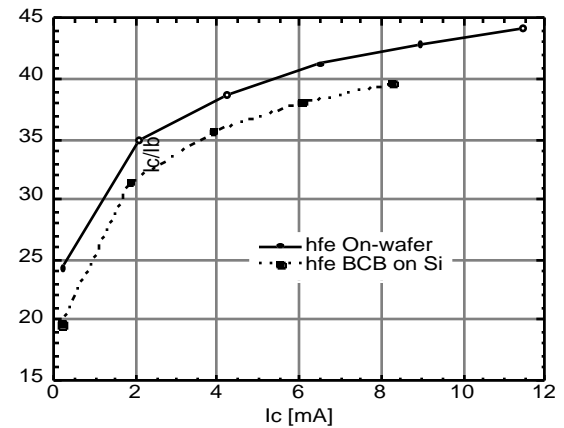


Figure 6 Gummel plot of HBT before and after bonding to BCB on Si.

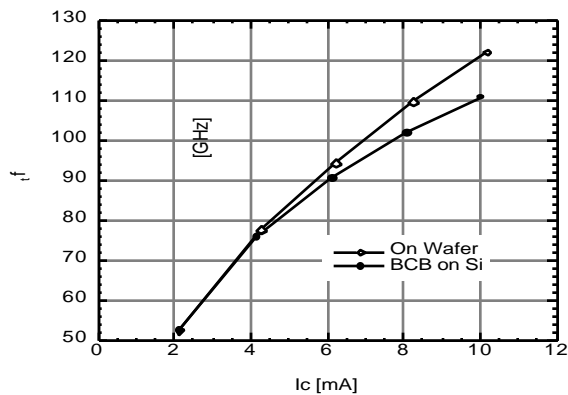


Figure 7 Comparison of HBT cutoff frequency before and after integration to Si.

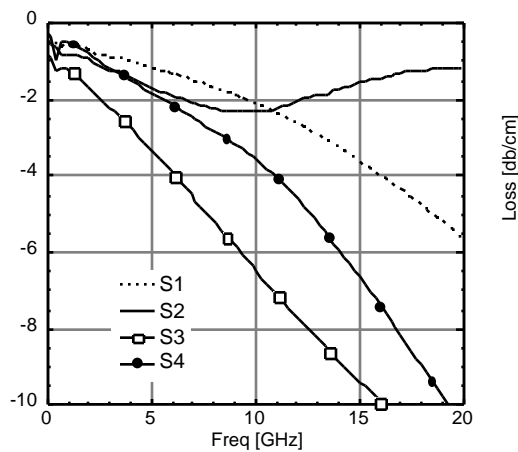


Figure 8 Loss of CPW lines on various substrates

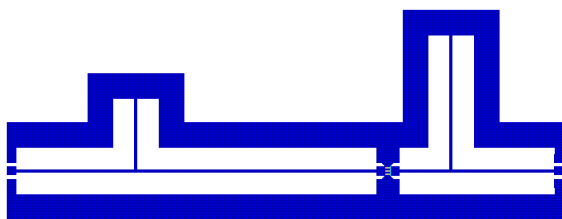


Figure 9 Layout of thin-film HBT amplifier

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