STUDENT PAPER

Development of an InP/GaAsSb DHBT MMIC Process with a Teflon AF Interlevel Dielectric

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ABSTRACT

In the present work we report the development of and first results for a millimeter-wave integrated circuit (MMIC) process for applications based on InP/GaAsSb double heterojunction bipolar transistors (DHBTs) using amorphous fluoropolymer (Teflon AF) as the interlevel dielectric. Teflon AF is used instead of benzocyclobutene (BCB) which degrades device performance due to its high temperature curing cycles. Additionally, Teflon AF exhibits superior dielectric properties with a dielectric constant of $\varepsilon_r = 1.9$ and a dissipation factor of 2×10^{-4} at 1 GHz. An inverted microstrip topology was chosen for the passive elements, and first results for transmission lines and amplifiers are shown in this report.

1. INTRODUCTION

Several groups have presented InP DHBT based MMICs at frequencies up to ~ 600 GHz [1, 2]. To the best of our knowledge all of these technologies use BCB as interlevel dielectric even though it has been shown that the necessary curing cycles at temperatures around 250 °C can degrade device performance [3]. We reported single devices using a Teflon AF planarization and showed no performance degradation when compared to air-bridge devices [4]. The newest generation of such devices is comparable to state-of-the art conventional DHBT technology, exhibiting simultaneous cutoff frequencies of $f_T / f_{MAX} = 503 / 780$ GHz [5]. To establish the suitability of Teflon AF as a MMIC interlevel dielectric we developed a complete MMIC process based on InP/GaAsSb DHBTs and two Teflon AF layers.

2. EXPERIMENTAL PROCEDURE

2.1. Process Description

In Fig. 1 the schematic representation of the wiring cross-section is shown. It allows for MMICs to be fabricated using DHBTs, resistors, capacitors and inverted microstrip transmission lines. The first part of the circuit process consists of the active device formation [4, 5]. The contact post metallization (Metal 1) also serves as landing pad for the vias, bottom electrode of the MIM-capacitors and can be used for dense wiring if necessary. Before the Teflon AF planarization (Teflon 1) the resistor metal is deposited. After dry-etching to expose the contact posts, the Teflon 1 layer thickness is approximately 1 μm. Vias are etched through the Teflon 1 to expose the resistors, the bottom electrode of the capacitors and via landing pads. In a next step, SiN is deposited and patterned to serve as insulator for the capacitors. The Metal 2 layer serves as signal conductor, contacts the DHBTs, the resistors and forms the top electrode of the capacitors. Subsequently, the interlevel dielectric layer Teflon 2 is deposited and vias are etched to access the Metal 2 layer. Metal 3 is electroplated and completes the inverted microstrip structure together with Metal 2. For applications above W-band the substrate has to be thinned to 50 μm and through-substrate vias become necessary. However, all results presented in this work were obtained with the full substrate thickness of 350 μm and consequently without through-substrate vias.

2.2. Transmission Line Results

For a Teflon 2 layer thickness of 8 μm, a 10 μm wide signal line on the Metal 2 level results in a transmission line with an impedance of approximately $Z_0 = 55\ \Omega$ and $\varepsilon_{r,eff} = 3.8$. Such transmission lines with a length of ~2 mm were characterized up to 220 GHz and the losses are shown in Figure 2. The measured loss is 0.9 dB/mm at 110 GHz and 1.6 dB/mm at 220 GHz, and shows a linear behavior over the whole frequency range. This means that for a transmission line without discontinuities, no parasitic modes are excited up to 220 GHz, even without thinning the substrate. However, if bends, junctions or other discontinuities are introduced, this is only valid up to the W-band.

2.3. W-Band Amplifier

Several circuits including 1- and 2-stage amplifiers at W- and G-band as well as oscillators at various frequencies were fabricated in a first run. Since the substrate was not thinned results at G-band are not ready to be published. As a proof of concept we present a simple one-stage W-band amplifier consisting of a single common-emitter DHBT, matching circuit and de-coupled DC-feed and RF lines. The mask layout is shown in Fig. 3 with the RF input on the left and output on the right. The DC supplies are at the top and bottom. From simulations we expected the amplifier to exhibit 12 dB of gain from 70 GHz to 110 GHz with input and output matching better than –6 dB. In Fig. 4 the measured S-parameters are plotted showing gain of 15 dB at 50 GHz which then drops to 9 dB at 110 GHz. Output matching is better than –5 dB over the whole frequency range, while input matching is worse than expected. Isolation is lower than –25 dB as expected from simulation.

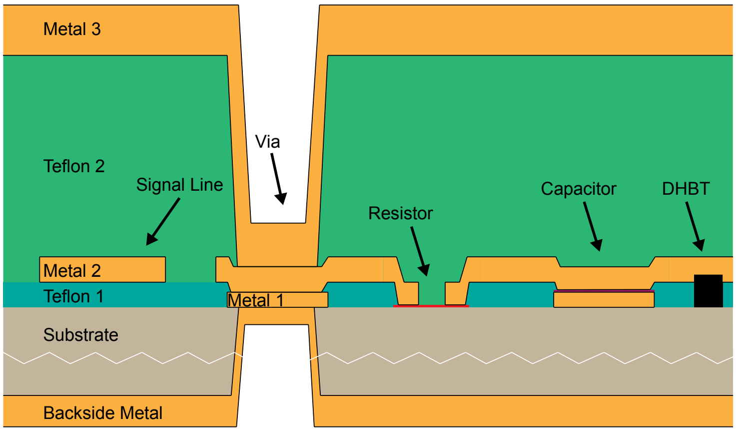

Fig. 1: Schematic representation of the wiring cross-section for the MMIC process developed in this work.

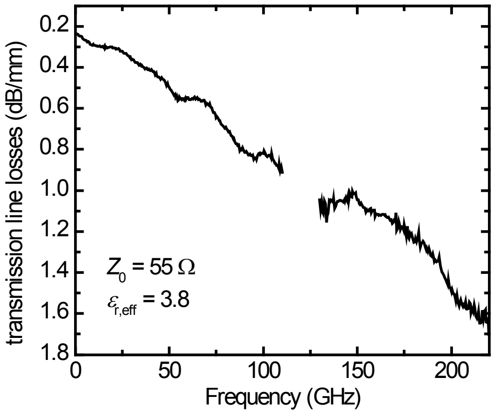

Fig. 2. Measured loss of a 10 µm wide inverted microstrip transmission line up to 220 GHz. The impedance of the line is 55 Ω and $\varepsilon_{r,eff} = 3.8$.

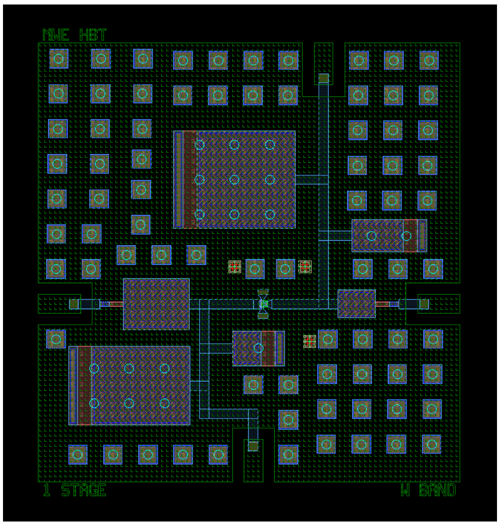

Fig. 3. Mask layout of a one-stage W-band amplifier consisting of a single common-emitter DHBT. The RF-input is on the left and the RF-output is on the right. DC supply pads are at the top and bottom of the circuit.

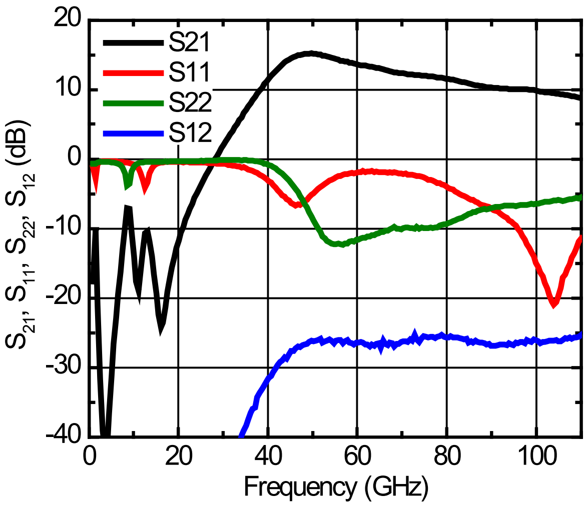

Fig. 4. S-parameters of a one-stage W-band amplifier. The gain is 15 dB at 50 GHz and drops to 9 dB at 110 GHz. Isolation is better than –25 dB over the entire frequency range.

3. CONCLUSIONS

We have developed a complete MMIC process including a design-kit based on InP/GaAsSb DHBTs with Teflon AF as interlevel dielectric. The transmission lines and a W-band amplifier results confirm the process suitability for MMIC design. Multiple causes for differences between the simulated and measured results have been identified, the design-kit models updated, and the next generation of circuits is currently under development.

4. REFERENCES

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