# MODELLING OF PASSIVE ELEMENTS FOR COPLANAR SIGE MMIC'S

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## ABSTRACT

As the first step in the development of coplanar SiGe MMIC's, modelling and experimental results on passive components are presented. The investigations demonstrate that parasitic effects induced by passivation of high-resistivity silicon substrates play an important role. Efficient CAD tools are developed and verified by comparison to measurements.

## MOTIVATION

The recent advances in the area of SiGe Heterostructure Bipolar Transistors (HBTs) open new possibilities for Si-based concepts. Together with the availability of high-resistivity substrates, SiGe MMIC's for frequencies beyond 20 GHz become feasible [1, 2, 3]. This paper reports on results obtained in the course of developing such an integration technology as well as the necessary CAD environment. The coplanar concept is used since it provides advantages with regard to both electrical performance and process technology, such as the elimination of backside processing and easy access by on-wafer probing.

## PARASITIC EFFECTS

On GaAs, the loss characteristics of MMIC elements with miniaturized dimensions are dominated by metallic loss. For high-resistivity material, this situation applies to the Si case as well. However, previous work (e.g. [4]) indicates that the electrical properties near the Si substrate surface may severely deteriorate during processing, particularly when depositing passivation layers. The phenomenon can be explained by inversion effects resulting in a conducting sheet at the Si surface below the passivation.

In order to clarify this the behaviour of coplanar transmission lines (CPW) is studied. First, a standard process is applied with the metallization on top of the SiN layer. The wafers are of the FZ type with a resistivity of more than 8,000Ωcm. In Fig. 1 the measured CPW propagation constants are plotted and

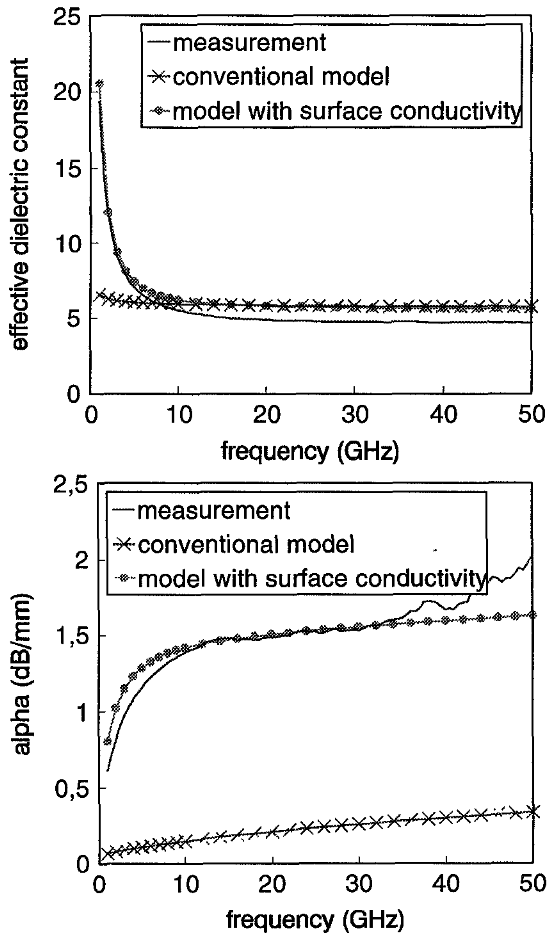


Fig. 1: Effective dielectric constant $\varepsilon_{reff}$ and attenuation $\alpha$ against frequency for a coplanar waveguide with 20$\mu$m wide center strip and 50$\mu$m ground-to-ground spacing: comparison of measurements on a passivated high-resistivity Si substrate with theory (conventional case [5] and revised model including a conducting layer below the passivation).





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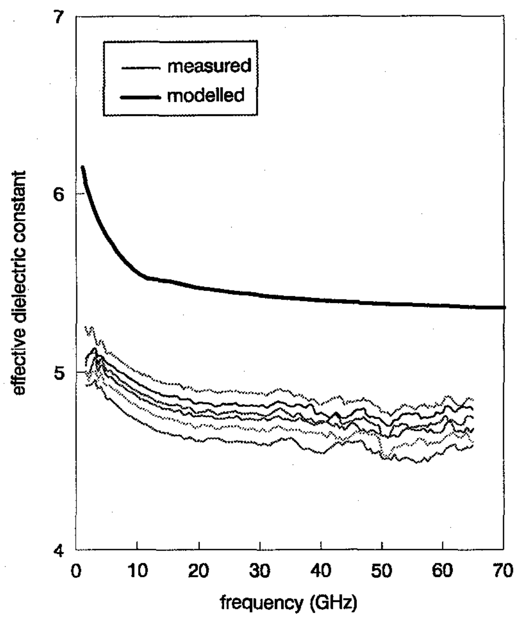


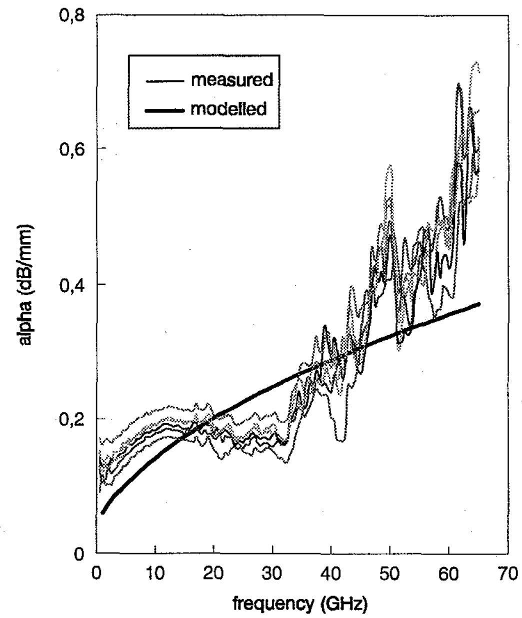
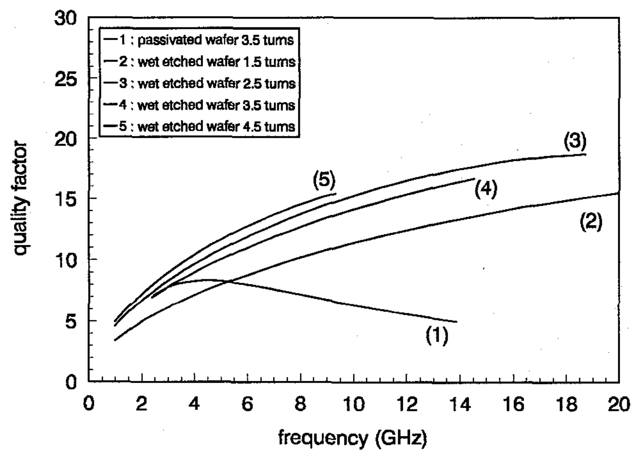




Fig. 2: Effective dielectric constant $\varepsilon_{reff}$ and attenuation $\alpha$ after etching (wafer map and model [5], for line data see Fig. 1).

compared to theory [5]. As can be seen the attenuation for the passivated wafer is considerably larger than expected, which is not acceptable for MMIC application. Also, the frequency dependence of the effective permittivity $\varepsilon_{reff}$ and the characteristic impedance deviate from the conventional case. If one extends the model [5], however, taking into account a resistive sheet at the substrate surface below the SiN, the measurements can be reproduced with good accuracy (see dots in Fig. 1). This finding supports previous observations and makes clear that processing has to be modified in order to meet MMIC requirements.

In a second step, the wafer was treated alternatively by a dry-etching and a wet-etching process that removed the SiN in the non-metallized areas, e.g. in the slots between the conductors of the CPW. As depicted in Fig. 2, such a treatment causes the parasitics to vanish almost completely for frequencies beyond 2 GHz. The line is modelled by a quasi-TEM approach [5] that includes finite metallization thickness, conductor and substrate losses. It is interesting to note that the $\varepsilon_{reff}$ values in Fig. 2 are lower than predicted, also although the special surface geometry (passivation layer etc.) was taken into account. The deviation corresponds to a reduction of about 10% in the $\varepsilon_r$ value for the Si substrate. This effect needs further investigation.

## SPIRAL INDUCTORS




| number of turns | 1.5 | 2.5 | 3.5 | 4.5 |
|---|---|---|---|---|
| inductance in nH | 0.5 | 1.3 | 2.3 | 3.8 |
| $f_{res}$/GHz | 38 | 26 | 17 | 13 |

Fig. 3: Spiral inductors on Si: Internal resonant frequencies $f_{res}$ and quality factor $Q$ (the values are calculated from the common measurement-extracted equivalent circuit, the quality factor refers to that of a LC resonator with an ideal capacitor connected in parallel).

As a typical example for lumped elements, Fig. 3 provides data on spiral inductors. Except for the 1.5-turn case, all spirals are realized in an air-bridged version with elevated conductors. Resonance frequencies $f_{res}$ and quality factor $Q$ compare well with equivalent GaAs components (see also [6]). For the 1.5-turn configuration, a resonant frequency of 38 GHz is achieved.

## DESCRIPTION OF PASSIVE NETWORKS

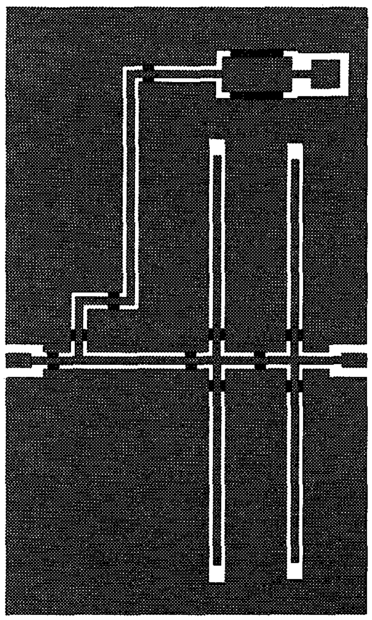


Fig. 4: Layout of coplanar matching circuit with bias feed.

Beyond the transmission-line case, models for the most common coplanar discontinuities and junctions have been developed. This comprises T- and cross-junctions as well as bends and air bridges. The descriptions are derived by means of a 3D full-wave analysis. A frequency-domain Finite-Difference approach [7] is used for that purpose. Based on these results, simple descriptions are developed.

We use coplanar waveguides with miniaturized dimensions, i.e., a 50 micron ground-to-ground spacing. Consequently, the parasitics remain relatively small and, in contrast to the transmission lines, simple descriptions are sufficient for the discontinuities, which is a very attractive feature with regard to circuit design. In most cases, the introduction of length extensions for the elements yields the required accuracy, which is easy to implement into the commercial design software. For transmission-line description, on the other hand, a user-defined model according to [5] is employed.

Fig. 4 shows the layout of a coplanar circuit that is used as output network for a SiGe HBT oscillator. Figs. 5 and 6 present the measured data and the predicted results using the afore-mentioned models. Both curves refer to the wafer with SiN removed by wet etching as explained above. Generally, we find favorable agreement. The discrepancies for $S_{21}$ in the frequency range above 50 GHz are due to measurement errors occurring for magnitude values lower than -30dB.

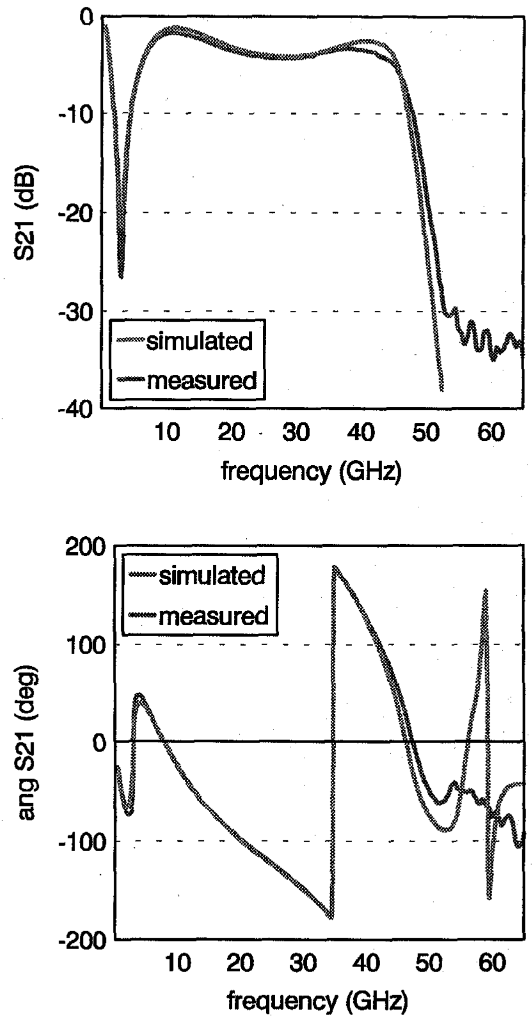



Fig. 5: Reflection coefficient $S_{21}$ (magnitude and phase) of the matching network of Fig. 4: comparison between measurements and simulation.

## CONCLUSIONS

- Standard Si passivation processes deteriorate the electrical properties of high-resistivity Si substra-

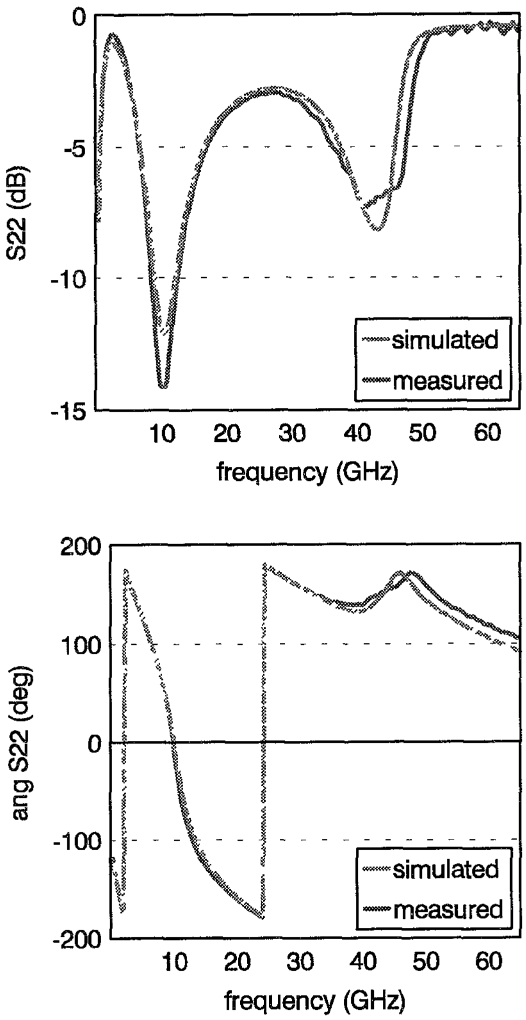



Fig. 6: Transmission coefficient $S_{22}$ (magnitude and phase) of the matching network of Fig. 4: comparison between measurements and simulation.

tes. A parasitic conducting layer below the passivation is induced, which renders such structures unsuitable for MMIC application.

- If these effects are avoided by suitable processing, the electrical performance of transmission lines and lumped elements such as spiral inductors is comparable with the GaAs case.
- The coplanar concept proves to be advantageous also for SiGe MMIC's: Except for the transmission lines themselves, simple models for discontinuities and junctions yield good predictions. The accuracy of the developed tools is demonstrated by comparison to on-wafer measurements for a passive matching network of relatively complex geometry.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