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Investigation on the effect of external mechanical stress on the DC characteristics of GaAs microwave devices

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ABSTRACT

Stress control is a main factor in the operation, performance and reliability of GaAs devices. A precise understanding of the impact of the mechanical stress on the performance and reliability of GaAs devices can lead to the improvement of the device design and packaging. Most of the time, process flow parameter modifications help to change internal stress in multilayer properties and this has a direct impact on the electric parameters. Mechanical wafer bending is the method usually used to investigate the effects of external stress on Gallium Arsenide (GaAs) devices.

The aim of this work is to quantify the sensibility of GaAs microwave devices used for Space applications under mechanical external stress in order to estimate the impact of packaging. In this innovative work, a bending-by-buckling system has been used to apply external mechanical stress on a single GaAs microwave die. To evaluate the value of this stress in device structure and precisely near the channel of the pseudomorphic High Electron Mobility Transistor (pHEMT), simulation based on the Finite Element Method has been carried out.

The stress was increased gradually from 0 to ~210 MPa (in tension and compression) and then reduced from ~210 MPa to 0. The experimental results demonstrate that the threshold current changes linearly and reversibly in the range of the applied stress. The shift in the threshold current and voltage of the pHEMT was analysed by considering piezoelectric effects.

1. Introduction

GaAs-based devices such as Monolithic Microwave Integrated Circuits (MMIC) with pseudomorphic High Electron Mobility Transistor (pHEMT) are often used for specific applications including low noise amplifier, radar, fibre optic data transmission systems [1]. The device structure consists of very thin active layer GaInAs epitaxially grown on Gallium Arsenide (GaAs) substrate, thin film metallic gates and insulating/passivating films. According to the deposition conditions, there usually exist residual stresses in the thin films and layers due to the lattice and thermal mismatch between epilayer and substrate [2]. Stress can also be introduced during the packaging processes or during operation due to differences in the thermal expansion coefficient (CTE) [3]. Previous investigation has revealed that microwave devices are sensitive to thermal stress due to testing at elevated temperature [4]. Therefore, for the GaAs microwave device, it is desirable to study the effect of an external mechanical stress on its properties for example the DC characteristics for a better understanding of the device performance. Indeed residual stress may be varied using several process parameters such as deposition temperature, pressure, gas nature or etch rate. However fabricating a number of different wafers for a complete design of experiments would be too expensive and not sensible for an investigation. Furthermore it is difficult to accurately quantify the amount of the residual stress present in the device. Also, modifying the process flow to alter the internal stresses in the dice can impact other characteristics [5–7] (energy band, wavelength, DC characteristics, RF measurements…). Therefore, applying known external stress by e.g. mechanical bending is a good solution to perform controlled stress experiments. Mechanical wafer bending is a simple and cost-effective way to investigate the underlying physics of stress in semi-conductors [1]. Several methods have been used to externally apply mechanical stress to semi-conductors. The first piezoresistance measurements by Smith [8] were achieved in 1954 by hanging weight from slabs of semi-conductors. This method requires large samples and was very limited. Year after year, cantilever bending systems have been developed and often used in micro-electromechanical system (MEMS) for transducer and resonant applications. Four point bending systems improves significantly the stress homogeneity constant between the two internal rollers. Thus recently H. Zhu et al. [9] have applied four-point bending approach to GaAs single quantum well laser diode. However, whatever the configuration, it is difficult to apply a uniform stress, either in the plane or out of the plane, to a single die a few millimetres long. All these methods require

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special equipment (displacement and force sensors…) associated with characterisation bench but they are limited in some cases by the lack of free area left for die surface observation.

In this work, we quantify the sensitivity of GaAs MMIC dice under external mechanical stress. By using a buckling system (Section 2), a uniform in-plane stress (either tensile or compressive) can be applied to the microwave device active surface (Section 3). The change of DC characteristics has thus been investigated (Section 4).

2. Experiments

In this section, experimental conditions are detailed from the sample preparation to set-up measurements on bench test.

2.1. Specimens

The GaAs MMIC used for this study include two 0.18 μm pseudomorphic High Electron Mobility Transistor (pHEMT) and $SiN_y/SiO_y/SiN_x$ Metal-Insulator-Metal (MIM) with a silicon nitride (SiN_x) passivation layer. The active components are based on GaAlAs/GaInAs/GaAs heterostructure of few nm thick grown by Metal Organic Vapour Phase Epitaxy (MOVPE) on (100) GaAs substrates. The die dimensions are ~100 μm (thickness) × 2000 μm (width) × 3000 μm (length).

The stress is applied to the die using a buckling system shown in Fig. 1. Because of the small size of the die (few mm), it was bonded on a Printed Circuit Board (PCB as a flexible support): designed with some electrical lines in other to ensure electrical connection for measurements. The PCB dimensions are 0.4 mm (thickness) × 6 mm (width) × 30 mm (length).

2.2. Buckling system and test bench

The buckling system (see Fig. 1) consists of two grooved plates in which the PCB support is slid, then electric connections are made. One plate is fixed and the other can be moved in *x* direction thanks to the micrometre. The in-plane stress applied results in bending by buckling mechanism. In our experiment, the critical *x* displacement level we apply must be less than 400 μm for the fear of die break. An initial orientation in *y* direction is necessary to select the tensile or compressive buckling modes. The micrometre provides smooth and accurate motion. The displacement is increased from 0 to 400 μm in 4 steps. For both tensile and compressive mode, a complete cycle has been performed (from 0 to 400 μm back to 0). The advantage of this method is the uniformity of the applied stress (better than 3 points bending) without the need for tools, as in four point bending. For characterisation, load pull measurements can easily be avoided to connectors use. Moreover, it needs less equipment. The active parts of the chip are located near its centre and the die is well bonded at the centre of the PCB support. Hence, the applied stress in the active layer and in the active parts is verified to be uniform and in-plane (see Fig. 3). The grooved plates are supposed to ensure only one degree of freedom: *z* axis rotation.

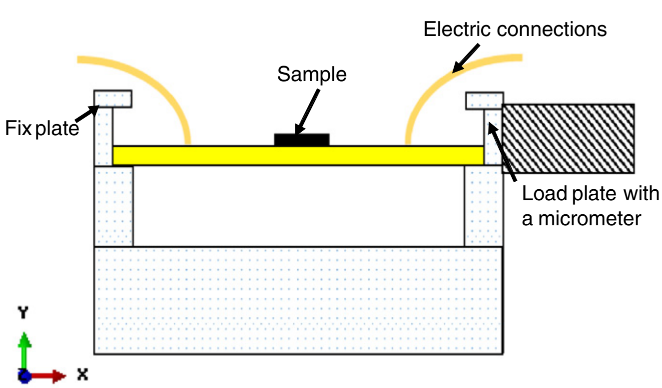

Fig. 1. The sketch of the buckling test bench.

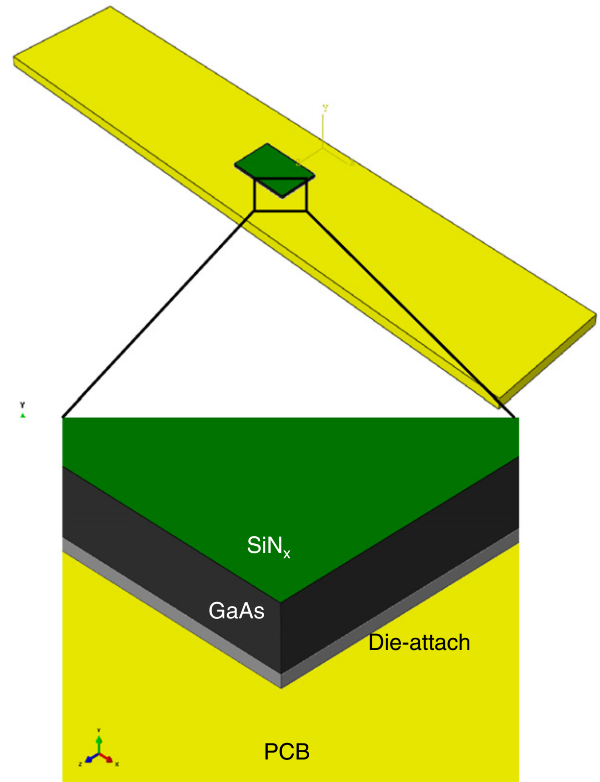

Fig. 2. Sample buckling setup 3D modelling with Abaqus CAE software and a zoom on the stack of the die.

The DC measurements have been performed with HP 4155 Semiconductor Parameter Analyser (SPA). For electrical characterisation of the pHEMT, drain voltage has been changed gradually from 0 to 3 V, gate voltage from −2 to 0.25 V corresponding to the limits of the foundry datasheet in DC characterisation. Only drain and gate currents have been measured. For both tensile and compressive mode, stress has been increased then decreased and measurements have been made at each step. The estimated mechanical stress is evaluated in the coming paragraph.

3. Simulation of sample buckling

This section focuses on the stress evaluation and it is made not at the top of the flexural support but precisely at the top surface of the GaAs substrate which is obviously the active layer position: heterostructure GaAlAs/GaInAs/GaAs is few nm thick compared with the 100 μm substrate. The stress distribution has been estimated with numerical simulation tools from Abaqus Standard® FEM software. A structured mesh composed of linear elements has been built and the contacts are assumed to be tie elements. Only applied mechanical stress are

Table 1
[2] Layers material properties and thickness.

	Young's modulus (GPa)	Poisson's ratio	Thickness (μm)
PCB	25.8	0.3	400
Die-attach	7.9	0.3	10
GaAs	85.5	0.31	100
SiN_x	150	0.3	0.15