Development and Mechanical Modeling of $Si_{1-x}Ge_x$/Si MQW Based Uncooled Microbolometers in a 130 nm BiCMOS

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***Abstract* — This paper presents the development of process integration and mechanical modeling of a Si1-xGex/Si MQW based uncooled micro-bolometer. The recent progress on layer transfer based integration scheme of Si1-xGex/Si based micro-bolometer into a 130 nm BiCMOS process is presented. The two important parts of the process integration, namely the layer-transfer and stress compensation of the arms are studied. The initial successful results on layer transfer and the FEM modeling for the stress compensation of the thin and narrow arms of the bolometer is presented. Finally, the developed FEM model is compared with the fabricated cantilevers. The results show that the developed FEM model has a very good matching with the experimental results; thus very convenient to use for the FEM modeling of the full bolometer structure.**

***Index Terms* — FEM modeling, thermistor, micro-bolometer, residual stress, Si/SiGe MQWs.**

I. Introduction

Thermal imaging systems based on uncooled microbolometer technology is getting more attractive for consumer electronics market due to its advantageous on maintainability, compactness, low weight, and cost [1]. Also, by the continuous development of the micromachining technologies in the field of MEMS gives the possibility to design and fabrication of advanced detector structures for thermal imaging systems. In parallel to those aspects, exploration of more efficient thermistor materials to be used as thermal detector in micro-bolometer devices increases. Among several candidates, different forms of SiGe received a significant attention in that sense. In particular, single crystalline SiGe is very promising due to its monocrystalline structure. Recently, IHP has achieved a significant results in Si/SiGe Multi-Quantum-Well (MQW) processing technology [2]. The developed high quality of super-lattice of Si1-xGex/Si MQW structure containing 50% Ge has been successfully processed and presented as a potential thermistor material with its high performance [3]. Further enhancement on this intrinsic thermistor device is presented in [4] to reduce the high resistance of the Si1-xGex/Si MQWs including high Ge concentration.

The principle operation of the micro-bolometer is based on a resistance measurement. The temperature change due to the IR absorption on the thermistor material, changes the resistance, based on the value of the temperature coefficient of Resistance (TCR). For a proper operation, the thermistor membrane needs to be thermally isolated from its surroundings, preferably in suspended form. Support arms connecting the heat sensitive thermistor detector to the readout integrated circuitry (ROIC) to ensure the thermal isolation as well as electrical conduction. In that aspect, the dimension and the material composition of the support arms have a significant role.. To have a good thermal isolation, the micro-bolometers support arms need to be extremely narrow and thin. However, at the same time these arms need to keep the base thermistor body in suspended form; thus needs to be mechanically stable. The selection of the material composition and the dimensions are very crucial for the final performance on both thermal isolation, electrical connection and the mechanical stability as well. Therefore, mechanical modeling of the bolometer arms has a significant importance on the final performance of the micro-bolometer.

In this paper, firstly a brief introduction to Si/SiGe MQW type thermistor device is given with the state of the art performance figures such as very high TCR of above 5. After that, the process integration concept is summarized and the two critical steps of the process integration, Si/SiGe MQW layer transfer and the mechanical modeling of the bolometer arms are studied. The initial process results for the successful layer transfer of Si/SiGe MQW is demonstrated. The mechanical modeling of the arms started with a FEM modeling of a very narrow and thin cantilevers. The developed model is fine-tuned with respect to the fabricated structures; thus a very accurate mechanical model is achieved. Finally, the developed mechanical model is used for the full mechanical simulation of the micro-bolometers. The results have shown that after optimizations, the developed narrow and thin arms has no significant effect on the final micro-bolometer structure.

II. Si/SiGe MQW Thermistor

A schematic cross-section view of the fabricated Si/SiGe MQW based intrinsic detector device based intrinsic thermistor device is shown in Figure 1. Epitaxial growth of MQW super-lattice structure and the intrinsic detector device fabrication details reported in [2] and [3], respectively.

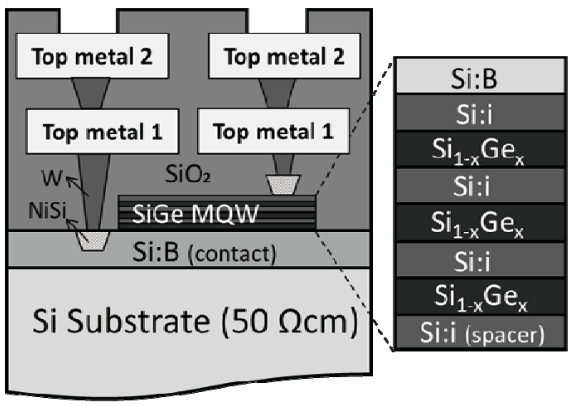

Figure 1. Schematic of the intrinsic detector device with three quantum well layers [2, 3].

Figure 2 shows the performance of the Si/SiGe MQW based intrinsic detector device for different Ge% in the quantum wells in terms of its most important figure of merits; TCR and noise. The details of the measurements are reported in [3]. The obvious advantage of more Ge content in the quantum wells is seen in Figure 2 (*left*). A very high TCR of 5.5%/K is obtained by the 50% Ge content whereas, noise values shown to be increased by the more Ge content (Figure 2 (*right*)). Nevertheless, the noise performance for 50% Ge content is still acceptable with respect to the state of the art values [3] and it can be further improved by the optimization of the doping level in the quantum well regions due to the reduced resistance values [4].

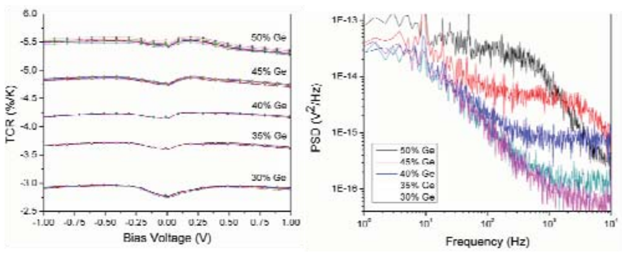

Figure 2. The performance of the Si1-xGex/Si MQW based intrinsic detector device for different Ge% in the quantum wells in terms of its most important figure of merits; TCR (*left*) and noise (*right*) [3].

III. Process Integration

Figure 3 shows the generic process integration of the bolometer on CMOS processed wafer [5]. The initial step for the integration is the layer transfer of the Si/SiGe MQW on top of the CMOS wafer. Since the process temperature to achieve defect free MQW is relative high (i.e. >600 ºC), the layer needs to be prepared on another wafer and transferred to top of the CMOS wafer. The process flow continues with the structuring of MQW, formation of the top, bottom vias and the via between bolometer arms and the top metal of the CMOS. Since the arms of the bolometer needs to be thermally isolated, the arms should be relatively thin and narrow. In next sections, layer transfer and the modeling of the arms are studied.

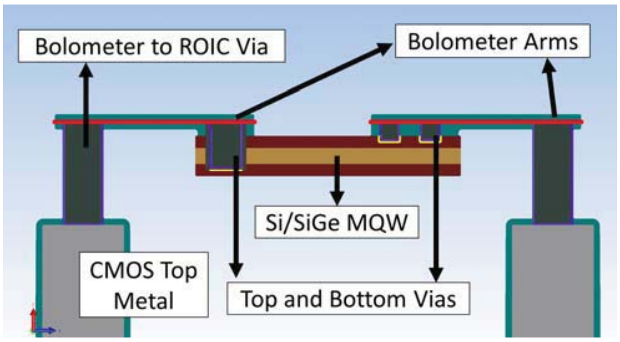

Figure 3. Generic view of the bolometer integration on top of CMOS wafer [5].

A. Layer Transfer

The layer transfer of the Si/SiGe on top of the CMOS wafer is performed by using oxide-oxide fusion bonding technique. This technique has challenges such as surface preparation for high bond quality without any void. Surface roughness optimizations is performed for a good quality of bonding on both CMOS and the MQW wafer. Finally, the quality of the bonding is controlled by using C-SAM (Confocal Scanning Acoustic Microscope). Figure 4 (left) shows the FIB cross section of the bonded wafers and the bonding interface. Figure 4 (right) shows the structures bolometer pixel after the layer transfer.

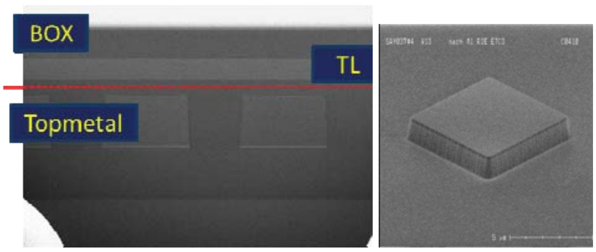

Figure 4. Cross section of transferred layer (left) and structured bolometer pixel after layer transfer (right).

B. Stress Compensation of Support Arms

The electrical connection to the ROIC circuit on CMOS wafer is done over the arms while the thermal isolation of the bolometer needs to be maximized with an enough mechanical stability. Therefore, a careful study on electrical, thermal and mechanical optimization is necessary for the arms. The developed FEM model based on three layer stack of SiN and TiN is given in Figure 5. The initial residual stress values of each layer is measured by standalone deposition of the layer followed by a wafer curvature technique and inserted to FEM solver. The FEM model for 20 um length and 1um width cantilever shows approximately 1.1 um deflection at the tip. For the comparison of the FEM model, the similar type of cantilever with the same material composition and thicknesses are fabricated. Figure 6 shows the fabricated 20um length cantilever beam with the exact same material and dimensions used in the FEM model on Picture 5.

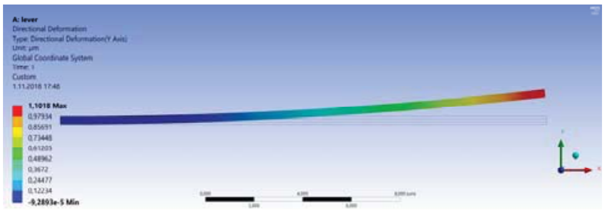

Figure 5. The FEM model of a 20um cantilever based on three layer stack with a deflection of 1.1 um.

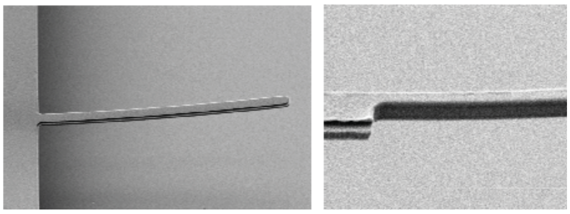

Figure 6. The fabricated 20 um length cantilever beam (left) and the FIB cut cross section (right).

The deflection of the cantilever beam is measured by Keyence 3D-Profilometer (Figure 7). The approximate deflection of 1.1 um is achieved which is in a very good match with the developed FEM model.

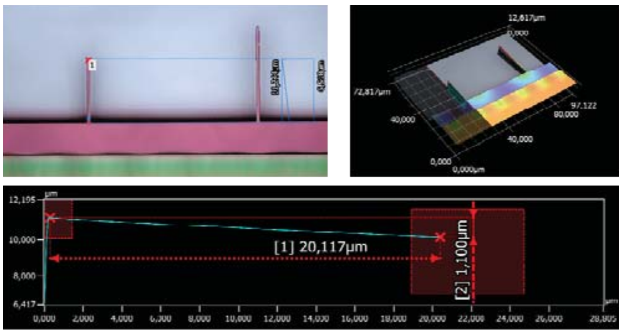

Figure 7. 3D-Profilometer results of the cantilever.

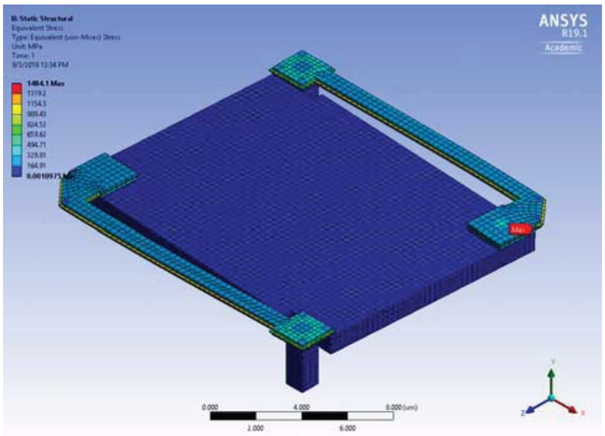

Figure 8. FEM simulation of bolometer structure based on the FEM model developed for arms.

Finally, the developed mechanical model for the arms are used in full FEM simulation of the bolometer structure (Figure 8). The results of the full bolometer modeling showed maximum deflections of less than 50nm for both vertical and lateral directions.

IV. Conclusion

In this paper, Si/SiGe MQW type thermistor device performance and the integration scheme of the thermistor as a bolometer structure on to a CMOS wafer is studied. As the two challenging steps, namely MQW layer transfer and the optimization of the support arms are detailed. Finally, the developed FEM model for the support arms are successfully inserted into the overall bolometer.

References

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