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# Improvement of Motional Resistance through Concave TSV Design and Modification for Static Capacitance of TSV-Based Resonator

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## Abstract

**In this paper, a concave TSV design of TSV-based resonator with 3D IC techniques is investigated. This novel concave TSV design displays the improvement of device characteristics. In addition, the influences of various isolation thicknesses on TSV-based resonator are also evaluated and discussed in this work. The innovated TSV design and optimized TSV-based resonator show the potential and feasibility in the next resonator generation.**

## 1. Introduction

In general, a resonator device needs to have good material stability and low aging rate in order to meet the frequency precision requirements. However, the challenges of future resonators include high material and manufacturing cost, difficulty in scaling down, and one chip sealing process[1-2].

Three-dimensional (3D) ICs, which enable the better performance and heterogeneous integration, have popularly received acknowledgment as the most promising solution in the next semiconductor generation [3-4]. The concept of resonator combining with 3D ICs has been proposed and showed the compatibility with semiconductor process in the previous work [5], while the entire device performances of the proposed concept are not fully studied yet in details. In this work, we further investigate the proposed device and improve performances with a novel concave TSV design. In addition, the modification of static capacitance is achieved by adjusting the thickness of isolation and entire integration processes.

## 2. Concave TSV Design and Deigned Degree of Isolation

Figs. 1(a)-(b) show the schematic diagram and SEM image of TSV-based resonator which is different from the conventional resonator device using metal cap with high temperature co-fired ceramic (HTCC) type. This designed resonator with 3D ICs is able to meet the demands on small size, cost effective technologies, and wafer level processes [5]. However, the poor motional resistance is found because of the fluidic Ag glue collapsed between Cu TSV and resonator. Therefore, the concave TSV design, in this research, integrating the Ag glue and resonator is used to solve the issue. The design can assure the structural integrity of resonator, Ag glue and TSV interconnection in Figs. 1(c)-(d). Furthermore, the influences of isolation degree in TSV-based resonator are investigated including the plated resonator, Ag glue and device housing itself. Consequently, the optimization of TSV-based resonator can be achieved through design rule and concave TSV design.

## 3. Results and Discussion

The variation of frequency and stability of TSV-based resonator with the concave TSV design are evaluated. The variation of frequency demonstrates the excellent results with a 10x improvement in Fig. 2(a). Fig. 2(b) shows the great stability of oscillating frequency after the cycling test. In addition, the range of motional resistance ($\triangle$R) is considered as the resistance variation under different power regions; as well as the qualified resistance stability after the cycling test in Fig. 2(c). The results show a smaller value of variation with designed concave Cu TSV structure, and the one without concave has extremely poor reliability and stability due to the collapsed Ag paste, causing the bad electrical connection. In Figs. 3(a)-(b), the delay time and quality factor of TSV-based resonator with concave TSV design are also improved significantly.

Figs. 4(a)-(b) show the vector network analyzer for measurement of TSV-based resonator and the corresponding Butterworth-Van Dyke equivalent circuit. The thickness of isolation modification increases recognition rate, which means enhancing the output of frequency response. To realize the frequency variation with load capacitance under different thickness of isolation, the parallel-loaded capacitance (from 1 pF to 30 pF) of TSV-based resonator is investigated in Fig. 5. Values of trim sensitivity at 5 pF are -2.69, -6.31 and -9.61 ppm/pF for devices with the various thickness of isolation, respectively. The results show that the devices can be more frequency sensitive with an optimized thickness of isolation. On the other hand, the drive current of TSV-based resonator is evaluated with a proper drive power of 100 μW, which depends on resonator specifications. The load capacitance versus drive current under fixed drive power of 100μW is plotted in Fig. 6. The results show the TSV-based resonator with thicker isolation is easier to be driven and has higher output of signal integrity. Consequently, this TSV-based resonator can be an attractive option for future resonator products. Overall, TSV-based resonator device with concave TSV design and optimized thickness of isolation indeed has an excellent electrical, frequency stability, and device characteristics.

## 4. Conclusions

In this paper, the concave TSV structure design is proved to reach an excellent electrical and frequency performances. We have investigated design and characterization of both TSV-based resonator devices with and without concave TSV design. The concave TSV design can solve the issue of motional resistance caused by the collapsed Ag glue before following cured process and integration. In addition, the modification of static capacitance is also accomplished through design of isolation. This design further demonstrates the potential and feasibility of TSV-based resonator for future advanced products.


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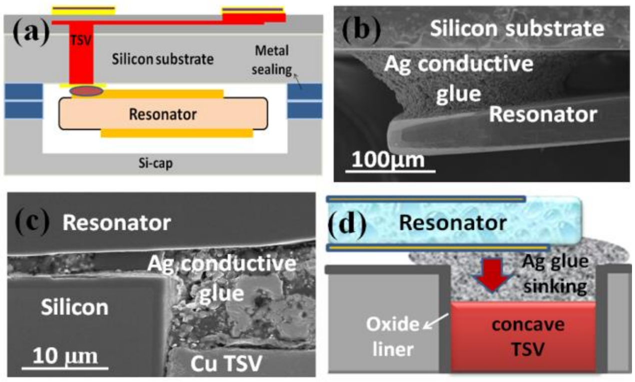


**Fig. 1** (a) The schematic diagram of TSV-based resonator device; (b) SEM image of Ag glue between resonator and TSV on Si wafer; (c)-(d) SEM and schematic cross-sectional image of concave TSV design.

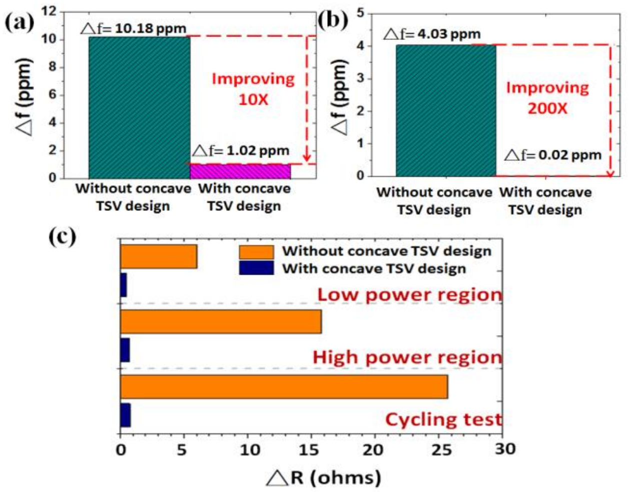


**Fig. 2** (a)-(b) The variation and stability of oscillating frequency; (c) the range of motional resistance (ΔR) under low, high power region and a cycling test.

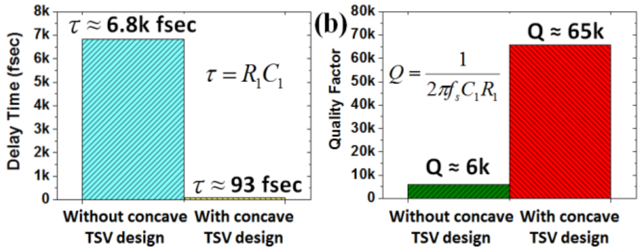


**Fig. 3** (a) Delay time and (b) quality factor of TSV-based resonator.

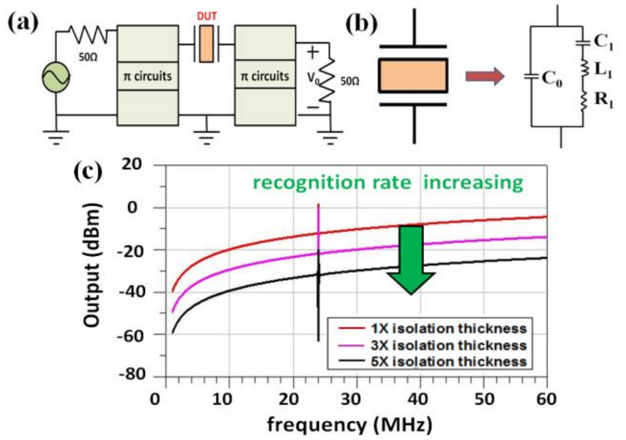


**Fig. 4** (a) Vector network analyzer; (b) Butterworth-Van Dyke equivalent circuit; (c) the response output versus frequency under different degrees of isolation.

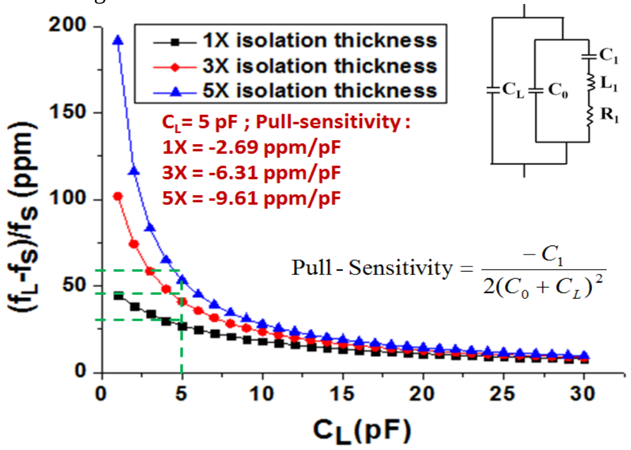


**Fig. 5** Frequency variation versus different parallel-loaded capacitance for devices under three kinds of degrees of isolation.

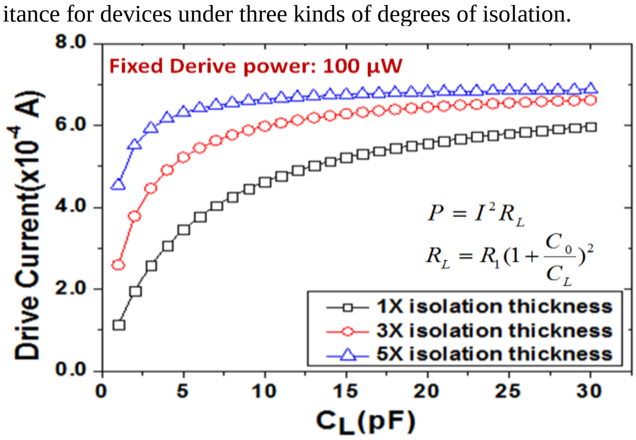


**Fig. 6** Drive current versus different parallel-load capacitance for devices under different degree of isolation.