A Faraday Cage Isolation Structure for Substrate Crosstalk Suppression

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***Abstract*—We have exploited a recently-developed, through-wafer via technology in silicon to implement a novel Faraday cage scheme for substrate crosstalk suppression in system-on-chip (SOC) applications. The Faraday cage structure consists of a ring of grounded vias encircling sensitive or noisy portions of a chip. The via technology features high aspect ratio, through-wafer holes filled with electroplated Cu and lined with a silicon nitride barrier layer. The new Faraday cage structure has shown crosstalk suppression of 40 dB at 1 GHz and 36 dB at 5 GHz at a distance of 100 μm. This is about 10 dB better than any other isolation technique previously reported.**

***Index Terms*—Isolation technology, mixed-signal circuits, RF circuits, substrate crosstalk, system-on-a-chip.**

I. Introduction

Recently, there has been much concern about substrate crosstalk in mixed-signal integrated circuits [1]–[8]. High crosstalk immunity is critical to enable one-chip systems that integrate noisy logic with sensitive low-noise RF and analog circuitry. Future systems will require densely-packed circuits operating at high frequency. Previous approaches to reduce substrate crosstalk include guard rings [1]–[3], SOI substrates [2]–[5], high-resistivity SIMOX substrates [6]–[8], junction-isolated wells [2]–[4], and metal-filled trenches [9]. Most significant results have come from junction isolation with guard rings, which reduced crosstalk by about 28 dB over bulk Si at 1 GHz when isolating both transmitter and receiver [3], and metal-filled trenches, which have demonstrated about 30 dB of isolation at 5 GHz and greater [9]. A key consideration when evaluating crosstalk isolation schemes is the footprint of the isolation structure. In [9], for example, the metal trench is 60-μm wide.

In this work, we present a novel Faraday-cage isolation structure that yields unprecedented crosstalk suppression. By exploiting a high-aspect ratio, substrate-via technology we recently developed [10], [11], the Faraday cage exhibits a small footprint. The Faraday cage consists of a ring of grounded substrate vias that encircle a noisy or sensitive circuit. At a transmission distance of 100 μm, the Faraday cage reduced crosstalk by 40 dB at 1 GHz and 36 dB at 5 GHz. The combination of a small footprint and high-frequency isolation makes this an ideal solution for substrate crosstalk suppression in one-chip systems.

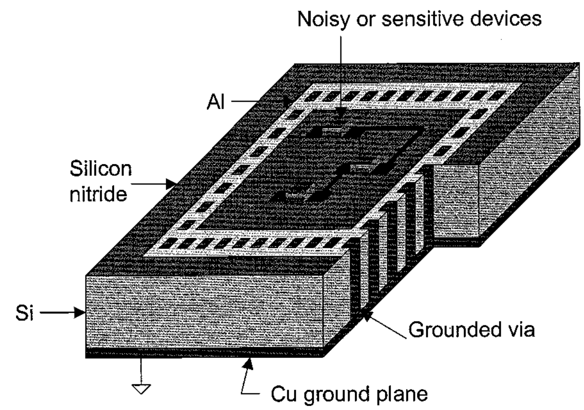

Fig. 1. Illustration of a Faraday cage surrounding a noisy or sensitive circuit as a novel isolation scheme for substrate crosstalk.

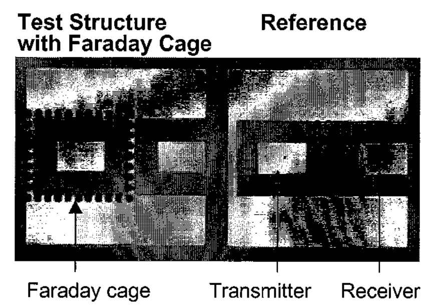

Fig. 2. Left: top view of the microwave test structure to evaluate isolation effectiveness of the Faraday cage. Right: reference structure. The transmitter–receiver separation or transmission distance is 100 μm. Each via of the cage is 10 μm in diameter and separated by 10 μm.

II. Experiment

The Faraday cage consists of a ring of substrate vias connected to the grounded backplane at the bottom of the substrate and shorted together by a ring of metal at the top (Fig. 1). The basic fabrication process described in [10], [11] consists of a Bosch RIE silicon etch to form high-aspect ratio via holes, PECVD silicon nitride for the insulating liner, and electroplated Cu to fill the vias. Cu CMP is used to smooth the top of the Cu vias after electroplating.

To determine the isolation effectiveness of the Faraday cage, we designed a two-port test structure in a coplanar, 50-Ω ground-signal-ground configuration (Fig. 2). $|S_{21}|$ was measured as the isolation figure of merit up to 6 GHz. The

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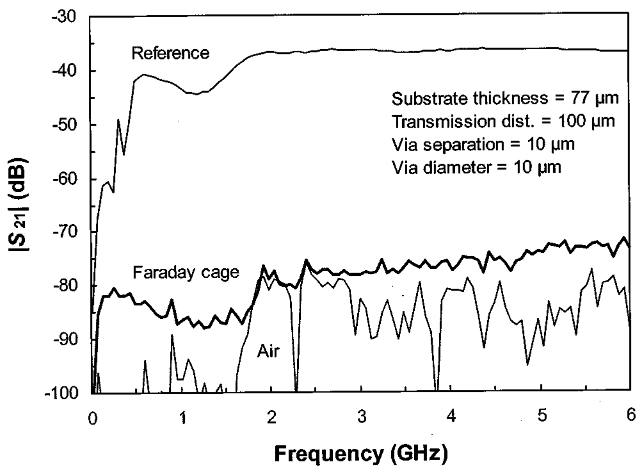

Fig. 3. $|S_{21}|$ versus frequency for a Faraday cage and reference structure at a transmission distance of 100 μm. This Faraday cage provides 38 dB of isolation at 5 GHz and 43 dB at 1 GHz. Also plotted is $|S_{21}|$ of the probes in the air.

transmitter and receiver pads varied in separation distance from 100 to 800 μm with the Faraday cage surrounding the transmitter pad. An identical reference structure was fabricated without the Faraday cage. In our first implementation, we used a 77-μm thick substrate and 10-μm diameter vias with an aspect ratio close to 8. Via spacing varies between 10 and 70 μm. Initial results presented in [10] revealed that the crosstalk through the air between the microwave probes masked the true crosstalk suppression of the Faraday cages. In these new measurements, we have introduced a grounded metallic screen between the two probes, which has reduced the air crosstalk by about 30 dB.

III. Results and Discussion

Fig. 3 graphs $|S_{21}|$ for a Faraday cage at a transmission distance of 100 μm. Also shown are measurements from the reference structure and with the probes in the air. Compared to the reference structure, the Faraday cage improves isolation by 43 dB at 1 GHz and 38 dB at 5 GHz. Measurements taken on several structures give an average crosstalk suppression of 40 dB at 1 GHz and 36 dB at 5 GHz. To our knowledge, these are the best values ever reported. They also represent a better than 20-dB improvement over [10].

Fig. 4 shows the impact of transmitter–receiver separation on crosstalk isolation at 5 GHz. For each transmission distance, this graph represents mean data obtained from at least three different die. The reference structure shows an expected decrease in crosstalk with distance. However, there is no apparent distance dependence of $|S_{21}|$ for neither the Faraday cage nor the air measurements. This demonstrates that the Faraday cage is particularly effective at short distances; its isolation effectiveness increases by about 12 dB at 5 GHz as the distance is reduced from 800 μm to 100 μm.

We have also examined the impact of via separation on isolation effectiveness. For a transmission distance of 200 μm, we fabricated Faraday cages with via spacings between 10 and 70 μm. Fig. 5 plots crosstalk suppression of the average of several die for these via spacings at 5 GHz. We found that there is no discernible dependence of isolation effectiveness on via

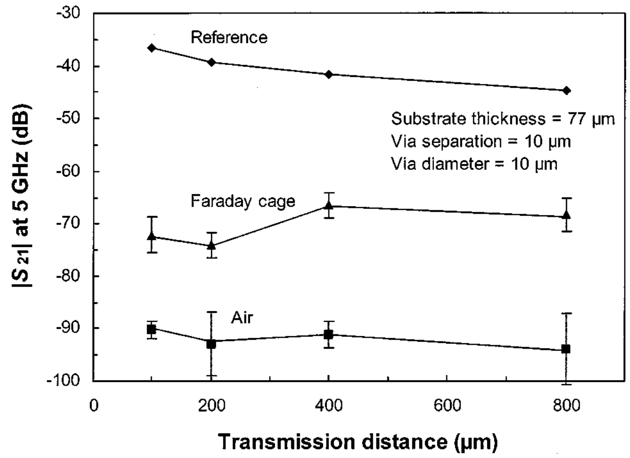

Fig. 4. Average $|S_{21}|$ at 5 GHz versus the transmitter–receiver distance for Faraday cage and reference structures. The error bars indicate one standard deviation away from the mean. The effectiveness of the Faraday cage is relatively constant with increasing transmission distance. The air measurements are well below the Faraday cage, indicating that the measurements are not limited by air crosstalk.

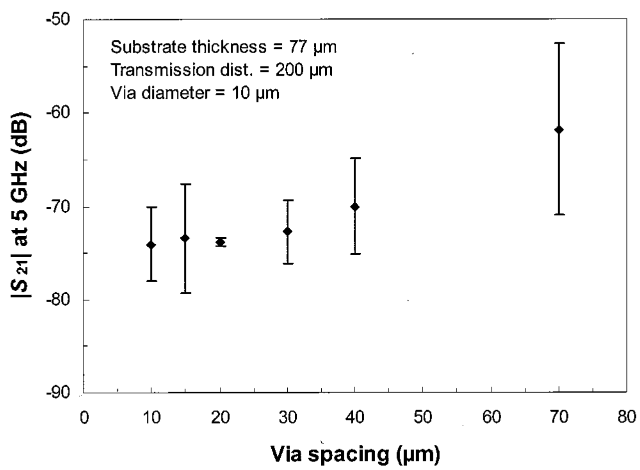

Fig. 5. Average $|S_{21}|$ versus via spacing of the Faraday cage at 5 GHz. No crosstalk dependence is apparent up to a 30-μm separation. There is slight degradation for larger via spacings.

density for via spacings up to 30 μm, and even beyond this separation, the degradation in crosstalk suppression is slight. This is an important result because sparse Faraday cages can be used in order to maintain the mechanical integrity of the substrate without compromising crosstalk suppression.

This paper demonstrates the feasibility and effectiveness of a new Faraday cage crosstalk isolation scheme. For a variety of experimental reasons, we have demonstrated this concept on a relatively thin substrate. Although further technology development will be required, the application of this concept to high-volume integrated circuits utilizing thicker substrates should not face fundamental limitations. The Bosch RIE process utilized here has been shown to produce high-aspect ratio structures on relatively thick substrates [12].

IV. Conclusion

We have used a novel substrate-via technology to demonstrate a new Faraday cage isolation scheme for SOC applications. The

Faraday cage improves isolation by 40 dB at 1 GHz and 36 dB at 5 GHz at a distance of 100 μm. The small footprint of the isolation structure and its high isolation effectiveness at short distances allows close packing of mixed-signal circuits. Since the crosstalk suppression of the Faraday cage is largely frequency independent, high isolation effectiveness is expected at higher frequencies.

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