Characteristics of Interconnect Lines with Patterned Ground Shields and its Implication for Microwave ICs*

Sang-Gug Lee and Hyuk-Yong Gwak
School of Engineering
Information and Communications University
58-4 Hwaam-dong, Yusong-gu,
Taejon, R. O. Korea, 305-348
and
Rex Lowther
Harris Semiconductor
MS 59-055, P. O. Box 883
Melbourne, FL 32902
Fax: 042-866-6227
E-mail: sglee@icu.ac.kr

I. ABSTRACT

The integrated circuit interconnects are experimented with patterned ground shields (PGS) at microwave frequencies. Measurement results demonstrate that the PGS can considerably reduce the power loss at high frequencies as the PGS shields the lossy silicon substrate. Furthermore, the PGS reduces the wave length of the interconnect line as a transmission line. The reduction of the wave length has significant implications in microwave IC design as the technique can be used to shorten the transmission line length for a given electrical length.

II. INTRODUCTION

With silicon-based integrated circuits, the power loss through the conductive silicon substrate tends to be a major limitation for the RF and microwave applications. The concept of PGS has been applied to the spiral inductors as a way to enhance the quality factor [1-2]. The PGS shields the electromagnetic fields as a ground plane between the spiral inductor and the lossy silicon substrate, yet the inductances are not reduced as the ground planes are patterned to stop the image current. However, the usefulness of the PGS inductor is in question because of the high parasitic capacitance between the inductor and the PGS. The high parasitic capacitance leads to low resonance frequency and therefore the low quality factors. This paper explored the usefulness of the PGS as a low loss interconnects as well as a high frequency transmission lines.

III. TEST STRUCTURES AND MEASUREMENT RESULTS

Figure 1, 2, and 3 shows the structure of the test patterns to investigate the interconnect characteristics. The test structures are fabricated on a 0.35-micron CMOS process, a 4-metal process with double poly-silicon layers. Figure 1 shows the test pattern with no object between the metal line and silicon substrate except the insulating SiO_2 layer. The pad size is 60μm x 60μm, the line length 1180μm, and the line width 10μm, respectively. Figure 2 shows the test pattern with PGS. It is the same structure as Fig. 1 except the PGS. The PGSs are implemented with a poly-silicon layer.

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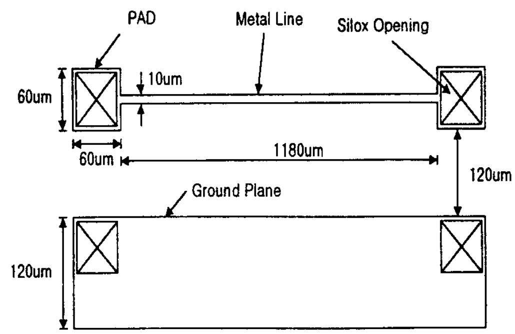

Figure 1: The no-PGS structure. There's no object between the metal line and the silicon substrate except the insulating SiO_2 layer. The pad size is 60(μm) x 60(μm), the line length 1180(μm), and the line width 10(μm).

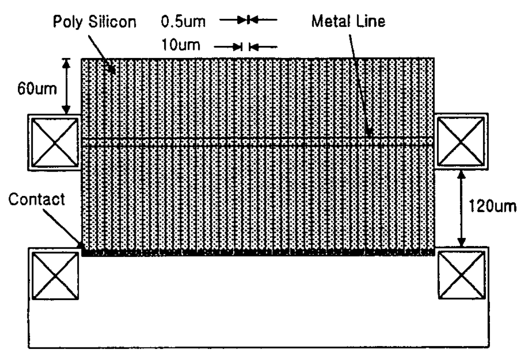

Figure 2: The PGS structure. The segments of poly-silicon strips are placed under the metal line and connected to ground plane through contacts.

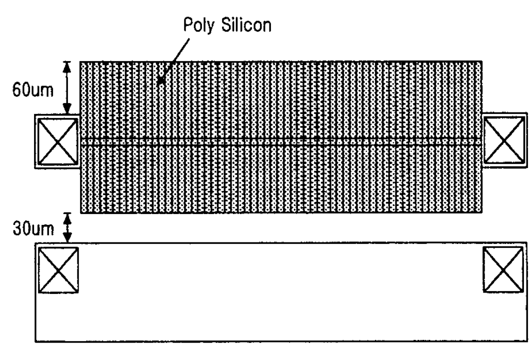

Figure 3: The floating-PS structure. The segments of poly-silicon strips are not connected to ground plane.

The Ploy-silicon PGS lines are sized for 10μm width and spaced by half a micron. Each PGS lines are tied to the ground plane through the contact as shown in the Fig. 2. The structure shown in Fig. 3 is basically the same as the one shown in Fig. 2 except that the patterned shields (PS) are floating, i.e., not tied to the ground. A two-port S-parameters are measured for the three test structures and their high frequency characteristics are investigated. S-parameters are measured from 500 MHz to 20 GHz.

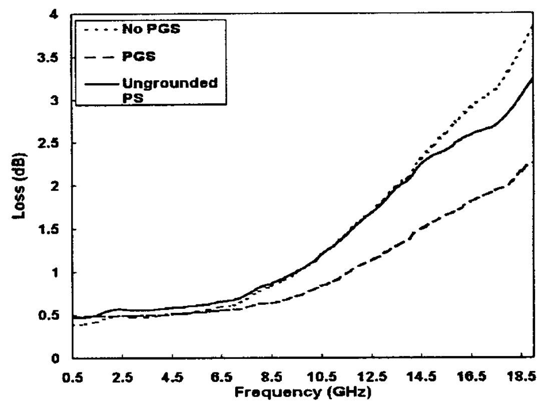

Figure 4: Interconnect line losses as a function of frequencies for no-PGS, floating-PS, and PGS for the length of 1180 μm.

Figure 4 is a plot of the power loss given by $loss = -10 \log_{10}\{|S_{21}|^2 / (1 - |S_{11}|^2)\}$ through the interconnect as a function of frequencies for no-PGS, floating-PS, and PGS for length of 1180 μm. In Fig. 4, the no-PGS line shows about 4 dB loss near 20 GHz while the PGS line shows about 2 dB which is only half the amount. Therefore, it is clear that the PGS does help to alleviate the power loss through the silicon substrate. This was expected from the PGS inductor characteristics. In Fig. 4, the power losses of the floating-PS lines show only a small improvement at high frequencies. As will be demonstrated more clearly in the transmission line characteristics, the small improvement in the loss of the floating-PS is an indication for the impact of the ground quality. The floating-PS line can be understood as a PGS line with poor grounding. As frequency increases, the floating PS tends to become like PGS through the capacitive coupling to the silicon substrate and then to the ground plane.

The characteristics of the interconnect test patterns as transmission lines are also investigated. The complex propagation constant (γ) and complex characteristic impedance (Z_0) are extracted using the formulas in [3]. The inductance and capacitance can then easily obtained from Z_0 and γ. [3]

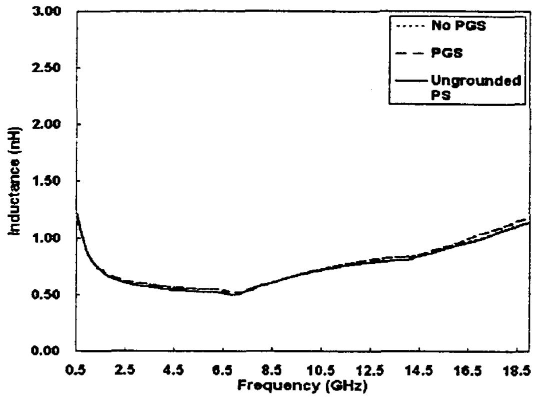

Figure 5: The inductances of the interconnects as a function of frequencies for no-PGS, floating-PS, and PGS for the length of 1180 μm.

Figure 5 shows the variations of the inductances of the interconnects as a function of frequencies for no-PGS, floating-PS, and PGS for the length of 1180 μm. In Fig. 5, the inductances of all three test patterns show almost same inductances as expected. This means that the PGS does stop the image current.

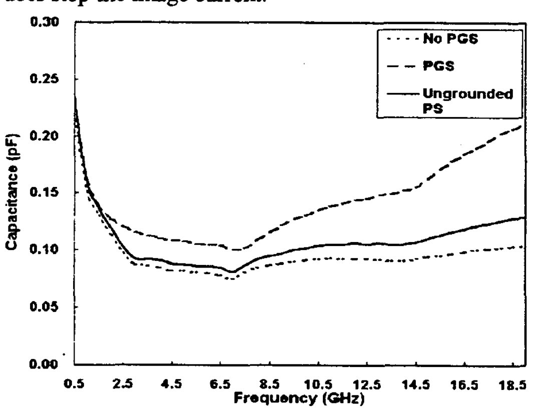

Figure 6: Capacitances of the interconnects as a function of frequencies for no-PGS, floating-PS, and PGS for the length of 1180 μm.

Figure 6 shows the capacitance variations of the interconnects as a function of frequencies for no-PGS, floating-PS, and PGS for the length of 1180 μm. As expected from the previous discussion, in Fig. 6 , the PGS increase the capacitance of the transmission line, almost twice the amount of no-PGS line at frequencies near 20 GHz. The increase in capacitance while the inductance remains the same has a significant implication as a transmission line. The wave length, λ, of the transmission line is proportional to $1/(LC)^{1/2}$ where L and C represents the inductance and capacitance per unit length of the transmission line. The increase in C for a given L leads to the increase in electrical length for the same length of transmission line. In other words, the PGS line shows shorter wave length than that of the no-PGS line.

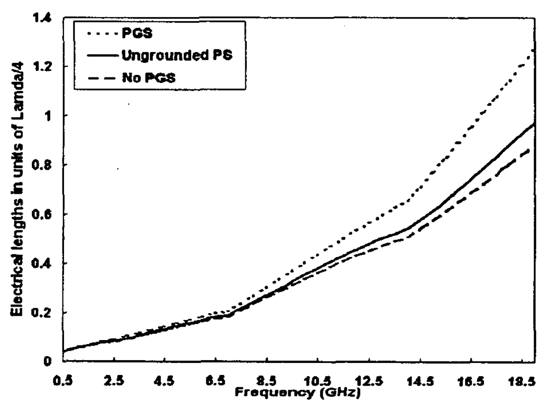

Figure 7: The electrical length of the interconnects in units of quarter wavelength (λ/4) vs. frequency for no-PGS, floating-PS, and PGS for the length of 1180 μm.

Figure 7 shows the electrical length in units of quarter-wavelength (λ/4) versus frequency for no-PGS, floating-PS, and PGS of the test patterns. As can be seen from Fig. 7, the transmission line length of 1180 μm corresponds to about $1.3*\lambda/4 = 0.325\lambda$ near 20 GHz with PGS, while the no-PGS shows about $0.9*\lambda/4 = 0.225\lambda$. This reduction in wave length, or the increase in electrical length for the given physical length of the PGS has a significant implication. Many microwave designs, at frequencies higher than 10 GHz, utilize on-chip transmission lines to realize various passive elements such as couplers, baluns, resonators, filters, or just as a capacitors and inductors.

The wavelength of the transmission line determines whether they can be included on-chip or not. Many transmission line based structures are typically composed of transmission line length of $\lambda/4$. Typically, at frequencies below 10GHz, transmission line based elements become too big to be incorporated into monolithic circuits. PGS can reduce the size of the transmission lines. From the previous discussion, the capacitance of the PGS, in principle, can be 10 to 1000 times higher or more than that of the no-PGS by controlling the oxide thickness between the interconnect line and the PGS, yet the inductance does not change. If the capacitance is 100 times higher, for example, then the wavelength of the PGS line becomes 1/10 of the no-PGS line. This means that, with proper design, even the RF circuits might be able to take advantage of the PGS transmission line as an on-chip passive elements. Furthermore, the shorter transmission lines allow higher quality-factor inductors and capacitors as the shorter metal length is required, and therefore the less series resistance.

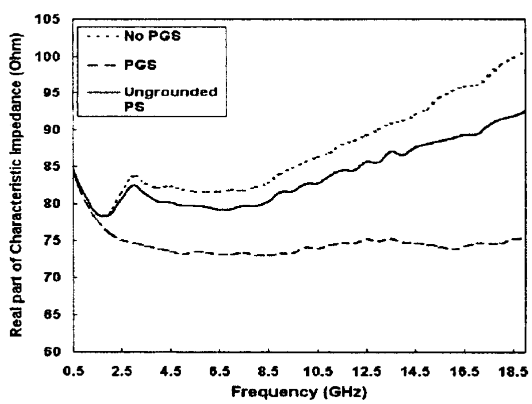

Figure 8: Real part of the characteristic impedance vs. frequency of the interconnects for no-PGS, floating-PS, and PGS for the length of 1180 μm.

Figure 8 shows the real part of the characteristic impedance versus frequency for no-PGS, floating-PS, and PGS transmission lines. The smaller values of the characteristic impedances in PGS line are expected as it is proportional to $(L/C)^{1/2}$. Again, in Fig.8 , we can clearly see that the floating-PS is like PGS with poor grounding as it shows some reduction in its characteristic impedance.

IV. CONCLUSION

The characteristics of the on-chip interconnect lines with PGS has been studied and compared with regular interconnects on a 0.35-micron CMOS process. Measurement results demonstrates that the PGS help reduce the signal loss as it shields the conductive silicon substrate from the interconnect line. In addition, the increase in the capacitance of the interconnect by the PGS, while the inductance remains the same, leads to a reduction in the wavelength of the interconnect as a transmission line. The reduction in the wavelength of the PGS transmission line opens up the possibility of implementing the smaller size transmission lines in microwave ICs and opens up the possibilities of implementing various transmission line based elements into RF ICs. The floating-PS is like a PGS with poor ground demonstrating the impact of the ground quality on the PGS characteristics.

V. References

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