Extended Abstracts of the 2002 International Conference on Solid State Devices and Materials, Nagoya, 2002, pp. 400–401

P2-9

# Guard-ring design for high-performance RF CMOS

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## Introduction

Recently, RF CMOS device has been applied to not only to Bluetooth (2.4GHz) [1] but also to higher frequency operation circuits such as 5GHz WLAN [2]. In the mixed analog and digital circuits, guard-ring design is very important for reducing substrate loss and suppression of substrate noise penetration.

In this paper, we propose the optimum guard-ring structures for MOSFETs with high fmax and low RF noise and inductors with high Q and stable inductance.

## Sample fabrication

Well and channel implantations were carried out after STI process. After 6nm gate oxidation and gate poly Si deposition, gate electrode was fabricated. Co salicide process was applied in order to reduce gate resistance after source and drain fabrication. Stacked spiral inductors were fabricated using 2nd, 3rd and 4th metal layers.

## fT, fmax and RF noise of MOSFETs

RF characteristics of MOSFETs with the three kinds of guard-ring structure were evaluated. Figure 1 shows typical layout of MOSFETs used in this experiments. Gate length was 0.25μm. The gate electrode was divided into fingers in order to reduce the gate resistance. In types A and B, the MOSFET is enclosed with guard-ring (Fig.1-a)). The distance (D) is 0.4 μm for type A and 50 μm for type B, respectively. Type C has ground region only near outermost source and the distance (D') is 0.4 μm (Fig.1-b)).

Figures 2 and 3 show the dependence of current gain (h21) on frequency and the dependence of fT on drain current for NMOSFETs. It was confirmed that both h21 and fT are almost the same in NMOSFETs with all guard-ring layouts. These results show the h21 and fT do not depend on the guard-ring design. On the other hand, significant differences in regard to unilateral gain (U) and RF noise in the MOSFETs. Figures 4 and 5 show the dependence of unilateral gain (U) on frequency and dependence of fmax on drain current for various guard-ring designs, respectively. The gain in type A and C is 5 dB higher than that in type B. The maximum of fmax in type A and C is also 20 GHz higher. Additionally, the drain current at fmax of 20GHz in type A and C is 80% lower compared with that in type B. Figure 6 shows the dependence of noise figures (NFmin) and associated gain (Ga) on drain current at 6 GHz operations. In type A, 0.5 dB lower NFmin and 1dB higher Ga were observed compared with those in type B.

In both type A and C, the distance between ground region and outermost source is 0.4μm, while it was 50 μm in type B. These results suggest that ground region should be close to outermost source in order to achieve higher gain, fmax and lower RF noise. It produces the reducing substrate loss between ground region and outermost source.

## Inductors

Figure 7 shows the guard-ring layout for inductors. Dimensions of the test inductors are outer = 145μm x 145 μm, width = 15 μm, space = 1.5 μm and turn number = 3.75. The guard-ring on pwell was formed by source and drain implantation in active area and Co-salicide process. The guard-ring layout in inductor is summarized in Table 1. There are the four kinds of layouts, A: without guard-ring, B: guard-ring (D=20μm), C: guard-ring with partial cut region (D=20μm), D: guard-ring with partial cut region (D=2μm). Figures 8 and 9 show the dependence of inductance and Q value of inductors on frequency for various guard-ring designs, respectively. Inductance value becomes lower due to the existence of guard-ring and the value is reduced further due to the entire guard-ring (Type B). This is because direction of induced current flowing in guard-ring is opposite to that in inductor. Additionally, Q value decreases due to entire guard-ring. Because, the higher induced current causes energy loss in the structure. In the cases of D=2μm and D=20μm, both the inductance and Q value were constant. These results show that distance of 2μm – 20μm between inductor and guard-ring is necessary in order to obtain stable inductance value and the cut region is needed for high Q inductor.

## Conclusions

The optimum guard-ring design was investigated for MOSFETs and spiral inductors. Ground region should be close to outermost source in order to achieve higher gain, fmax and lower RF noise. The distance of 2μm – 20μm between inductor and guard-ring is necessary in order to obtain stable inductance value and the cut region is needed for high Q inductor.

## References

[1] P. van Zeijl et al., Dig. ISSCC, p.86, 2002.
[2] D. Su et al., Dig. ISSCC, p.92, 2002.

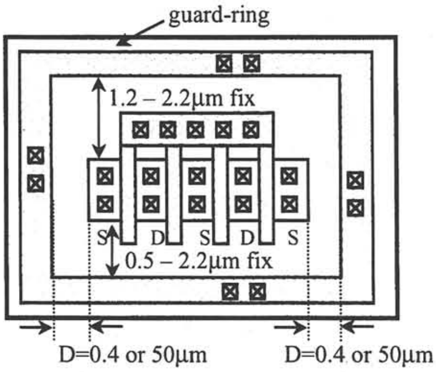

Fig. 1 a)

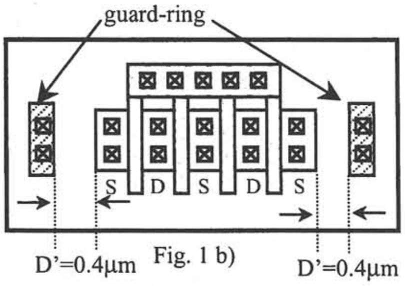

Fig. 1 b)

Fig.1 Typical layout of MOSFETs for RF measurement. Three kinds of guard-ring layouts were evaluated. Type A and B are shown in Fig. 1–a). D is 0.4μm for type A and 50μm for type B. Type C is shown in fig. 1-b). Type C has only ground region near outermost source, and D' is 0.4μm.

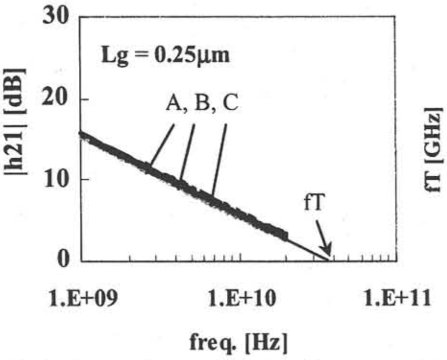

Fig.2 Dependence of |h21| on frequency for NMOSFETs with various guard-ring layouts.

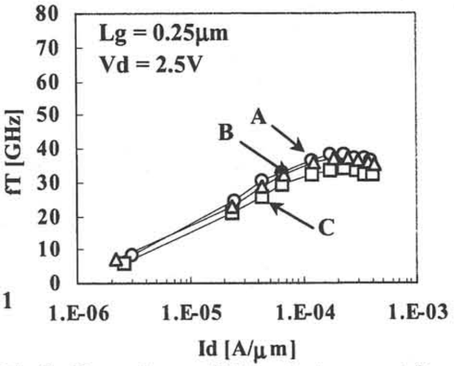

Fig.3 Dependence of fT on drain current for NMOSFETs with various guard-ring layouts.

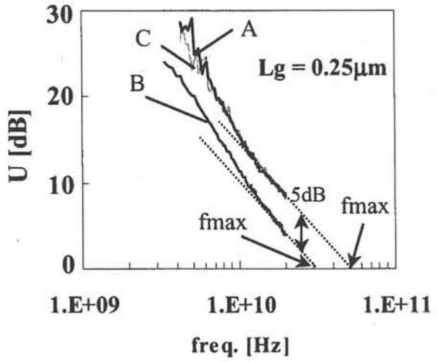

Fig. 4 Dependence of unilateral gain(U) on frequency for NMOSFETs with various guard-ring layouts.

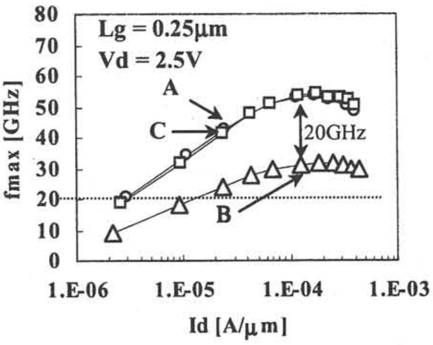

Fig.5 Dependence of fmax on drain current for NMOSFETs with various guard-ring layouts.

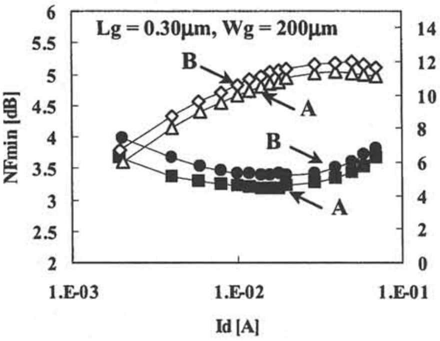

Fig.6 Frequency dependence of NFmin and associated gain (Ga) for type A and type B.

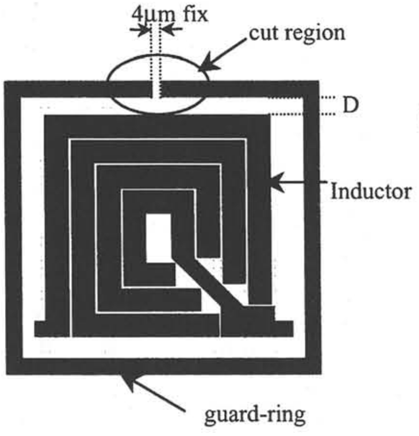

Fig.7 Guard-ring layout for inductors. D is the distance between inductor and guard-ring. Inductor has the guard-ring with partial cut region. The cut region length is 4μm.

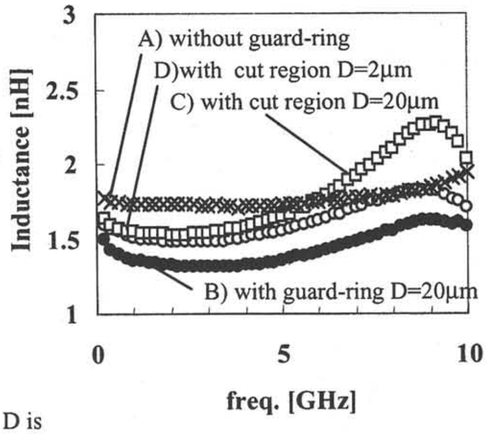

Fig.8 Dependence of Inductance on frequency for various guard-ring layouts.

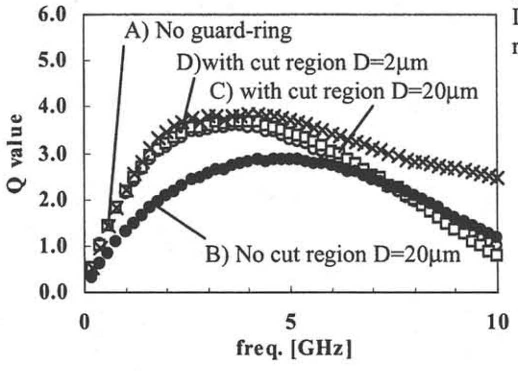

Fig.9 Dependence of Q value on frequency for various guard-ring layouts.

Table 1. Summary of guard-ring layout in inductors.

| | A | B | C | D |
|---|---|---|---|---|
| guard-ring layout | **Without guard-ring** | **With guard-ring** | **With cut region** | **With cut region** |
| D (μm) | **-** | **20** | **20** | **2** |
| L (nH) | **1.7** | **1.4** | **1.5** | **1.5** |
| Q value | **3.7** | **2.3** | **3.3** | **3.4** |