ESD PROTECTION DIODE STRINGS FOR IC CHIPS OF MINIATURE ROBOT APPLICATIONS

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Abstract - The integrated circuit (IC) chips have been used in miniature robots. To ensure the reliability of IC chips, the electrostatic discharge (ESD) issue should be considered. Several ESD protection diode strings for IC chips of miniature robot applications are implemented and compared in this work. According to the test results, the diode string with P+/N-well and P-/N+ diodes has higher ESD current-handling ability and lower leakage current. Therefore, this ESD protection diode string would be more useful for IC chips of miniature robot applications.

Index Terms - Electrostatic discharge (ESD) protection, IC chip, reliability.

I. INTRODUCTION

The robot miniaturization is important for microrobotic research. To achieve the target of size reduction, one way is offered by the micro-electro mechanical systems (MEMS) technology, which is based on the integrated circuit (IC) production process [1]. Besides, the IC chips have been implemented for control unit of miniature robots [2]. However, the IC chips are inherently very sensitive to electrostatic discharge (ESD) events [3], [4]. The ESD events can happen according to the different electrostatic potentials between two or more objects. The devices are usually damaged by ESD via the rapidly generated heat or the rapidly created strong electrical field. To predict the ESD immunity level of IC chips, the test method is known as the human-body-model (HBM) ESD test [5]. The minimum requirement for a commercial IC chip is to pass 2000V HBM ESD test [6]. The ESD protection design is needed to ensure the reliability of IC chips of miniature robot applications, as shown in Fig. 1. Diodes have been used as the ESD protection devices [7]. The ESD protection diodes are typically realized with shallow-trench-isolation- (STI-) bounded diodes. The P-type STI-bounded diode consists of P+/N-well, and the N-type STI-bounded diode consists of P-well/N+. The diode strings, as shown in Fig. 2, have also been used for ESD protection, such as the power-rail ESD clamp, mixed-voltage interface ESD protection, and radio-frequency (RF) ESD protection. However, the main drawback of using large-sized diode string for ESD protection is the leakage current. Some designs on the ESD protection diode strings to reduce the leakage current have been reported [8]-[10]. In this work, four ESD protection diode strings are implemented. This paper aims to compare the ESD protection designs those are suitable for IC chips of miniature robot applications.

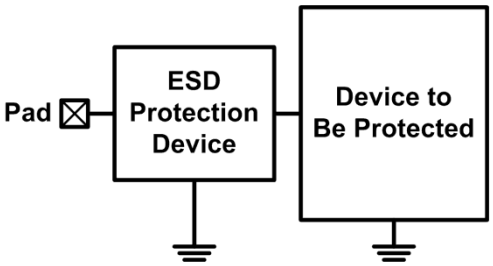


Fig. 1. ESD protection design for the device to be protected.

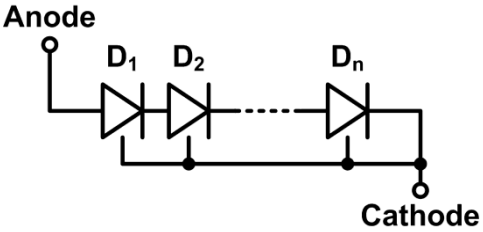


Fig. 2. Schematic diagram of ESD protection diode string.

II. ESD PROTECTION DIODE STRINGS

A. Type 1: P+/N-well Diodes

The conventional diode string utilizes P+/N-well diodes in CMOS technology [8]. For example, Fig. 3(a) shows the cross-sectional view of the conventional diode string with 2 stacked P+/N-well diodes.

B. Type 2: P-well/N+ Diodes

The diode string can also be realized by using P-well/N+ diodes with deep N-well to isolate the P-well from the common P-substrate [8]. For example, Fig. 3(b) shows the cross-sectional view of the diode string with 2 stacked P-well/N+ diodes in the triple-well technology.

C. Type 3: P-/N+ Diodes

The diode string utilizes P-/N+ diodes has been presented [9]. The P- implantation is a standard step in CMOS process to improve the turn-on ability of ESD protection NMOS [11]. Fig. 3(c) shows the cross-sectional view of the diode string with 2 stacked

P-/N+ diodes in the standard CMOS technology.

D. Type 4: P+/N-well and P-/N+ Diodes

Fig. 3(d) is the device cross-sectional view of the diode string with P+/N-well and P-/N+ diodes [10]. In this structure, one P+/N-well diode and one P-/N+ diode are merged together to form a silicon-controlled rectifier (SCR) path, that is P+/N-well/P-/N+. The SCR device with low turn-on resistance, low clamping voltage, and high ESD robustness has been reported to be useful for ESD protection [12]. During ESD stress, the diode string will turn on to discharge the initial current, and then the SCR path will turn on to discharge the primary current. Besides, by butting the P+/N-well and P-/N+ diodes, the N+ and P+ can be directly connected.

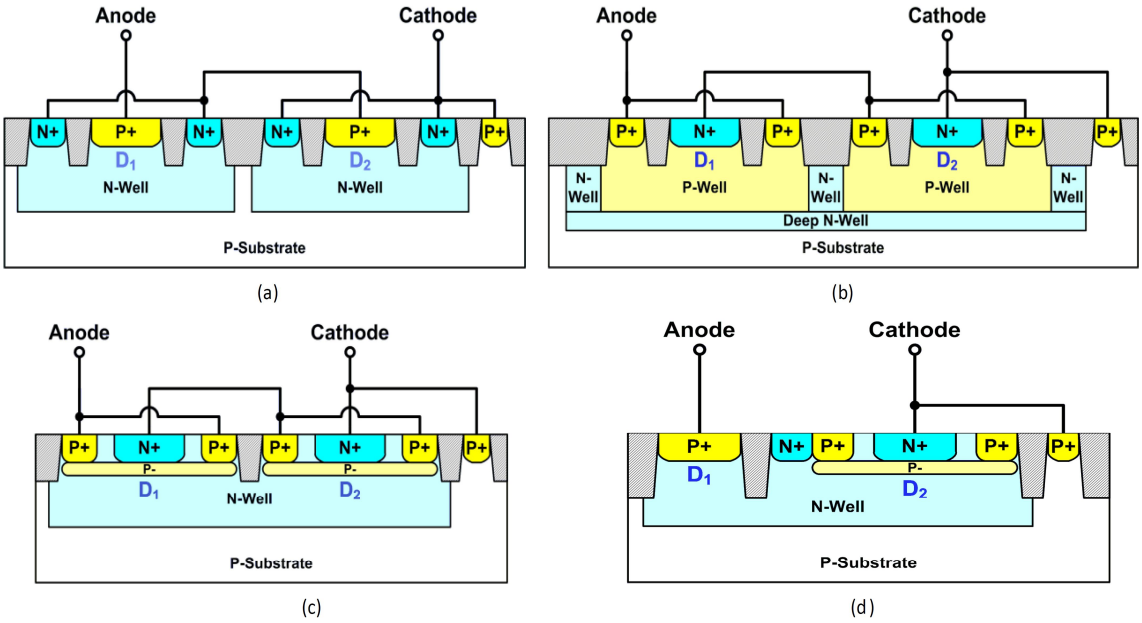


Fig. 3. Device cross-sectional views of diode strings with 2 diodes: (a) type 1: P+/N-well diodes, (b) type 2: P-well/N+ diodes, (c) type 3: P-/N+ diodes, and (d) type 4: P+/N-well and P-/N+ diodes.

III. MEASUREMENT RESULTS

The ESD protection diode strings with 2 and 6 diodes are implemented and compared in this work. A transmission-line-pulsing (TLP) system is used to investigate the I-V characteristics of the devices in the domain of ESD event. The clamping voltage during ESD stress must be less than the failure voltage of the device to be protected. The current-handling ability of each test device before failure voltage of 10V (I_{10V}) can be obtained from the TLP-measured I-V curves. The TLP-measured I-V curves of the ESD protection diode strings with 2 diodes are shown in Fig. 4, and those with 6 diodes are shown in Fig. 5. The I_{10V} of four diode strings with 2 diodes are 1.20A, 1.21A, 1.20A, and 1.44A, respectively, and those with 6 diodes are 0.70A, 0.65A, 0.56A, and 0.73A, respectively. With the higher I_{10V}, the results indicate that the type 4 diode string with SCR path can slightly improve the ESD current-handling ability.

The leakage current of the diode strings are measured. For 0.6V applications, the leakage currents of four diode strings with 2 diodes are 2.0nA, 1.8nA, 1.6nA, and 1.5nA, respectively. For 1.8V applications, the leakage currents of four diode strings with 6 diodes are 4.2nA, 3.7nA, 1.8nA, and 1.7nA, respectively. The leakage currents of these diode strings are listed in Table I. The figure of merit (FOM) is compared among the diode strings. The FOM considers the I_{10V} and leakage current

$$FOM = \frac{I_{10V}}{Leakage}$$

The FOM of four diode strings with 2 diodes are 0.6×10^9, 0.7×10^9, 0.8×10^9, and 1.0×10^9, respectively, and those with 6 diodes are 0.2×10^9, 0.2×10^9, 0.3×10^9, and 0.4×10^9, respectively, as listed in Table I. The type 4 diode string can perform the higher I_{10V} and lower leakage current.

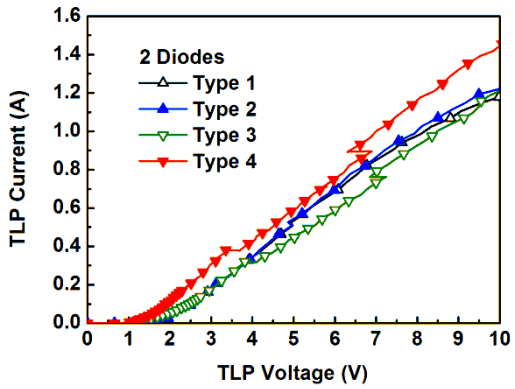


Fig. 4. TLP-measured I-V curves among different diode strings with 2 diodes.

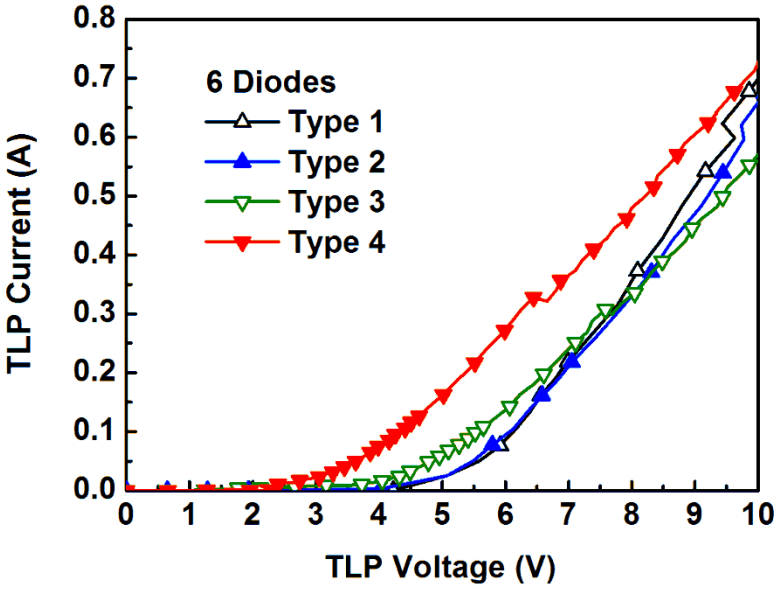


Fig. 5. TLP-measured I-V curves among different diode strings with 6 diodes.

Diode String		HBM Robustness (kV)	TLP I_{10V} (A)	Leakage (nA)	FOM (10^9)
2 Diodes	Type 1	4	1.20	2.0	0.6
	Type 2	4	1.21	1.8	0.7
	Type 3	4	1.20	1.6	0.8
	Type 4	4	1.44	1.5	1.0
6 Diodes	Type 1	4	0.70	4.2	0.2
	Type 2	4	0.65	3.7	0.2
	Type 3	4	0.56	1.8	0.3
	Type 4	4	0.73	1.7	0.4

CONCLUSION

It was known the IC chips are highly sensitive to ESD. We have examined four types of ESD protection diode strings in this work. Among the test devices, the type 4 diode string with P+/N-well and P-/N+ diodes has higher current-handling ability during ESD stressing, and lower leakage current under normal circuit-operating condition. Therefore, the type 4 diode string is more useful for on-chip ESD protection in IC chips of miniature robot applications.

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