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Analysis of the breakdown voltage of an area surrounded by the multi-trench gaps in a 4kV monolithic isolator for a communication network interface

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Abstract:
We analyzed the conditions to improve the dielectric breakdown voltage in the area surrounded by the buried oxide (BOX) film and the buried multiple trench gaps on the SOI substrate surface. We use an impedance model and determine the conditions to improve the breakdown voltage. One is to increase the impedance of the BOX, The other one is to reduce the impedance of the trench gaps. We confirmed them by simulation and the experimental results.

1. Introduction
An on-chip isolation is one of the most important technology for a compact communication network interface. There is a difficulty to overcome the trade-off between compactness and voltage tolerance. However, currently, they become important for low power interface, small space packaging in terms of an electrical strength for the sensor ICs. A multiple trench gap structure is good solution. Using this structure, an on-chip 2.3-kV 100-MHz multi-channel monolithic isolator IC has been achieved [1-2]. Further, that the breakdown voltage is improved to 4.0-kV without changing the chip size by being biased by the voltage divided by the Poly-Si resistors [3-4]. The purpose of this paper is to show analytical conditions to improve its breakdown voltage in the isolation device of these structures. In addition, by comparing the experimental results with the simulation, validity of the analytical model is to be confirmed.

2. Circuit analysis:
Figure 1 shows the schematic chip view of the isolated region surrounded by BOX and multiple trenches. We analysis on the voltage applied to the trench gap between the area 1 and the area 2. Breakdown between these two areas is arising under following conditions. 1) Breakdown of multiple trench gaps, 2) Breakdown of BOX. In this paper, we mainly analyze the breakdown condition 1). The equivalent circuit can be expressed by Figure 2, where Zu is the impedance of trench gap and Zb is that of BOX. Vc is the potential of area 1, Vs is the potential of area 2 and Vcs is the potential of the substrate. The breakdown voltage is determined by the sum of the shared voltage Vi (k=1 to N). When a certain trench gap in between is destroyed, breakdowns of other trench gaps start to occur like an avalanche. In order to maximize a breakdown voltage, a shared voltage should be equalized. From the symmetry of the area 1 and area 2, Vcs = (Vc-Vs) / 2. Then, N equals 2M. The voltage applied between area 1 and area 2 equals the sum of shared voltage from V1 to VN, which is expressed in formula (1). In the range of k≦M , formula (2) is satisfied. In the range of k≧M +1, formula (3) is satisfied. When each shared voltage becomes equal, formula (4) is satisfied. Dielectric strength voltage Vtol at this time was calculated by formula (5). There are two approaches to improve a breakdown voltage for the condition that Zu / Zb << 1. In total, there are three approaches summarized in table 1.

3. Confirmation by simulation
Figure 3 shows the dependency of breakdown voltage by the number of trench gaps. This shows that the breakdown voltage is limited by the unbalanced shared voltage shown in Figure 4. Figure 5 shows the dependency of breakdown voltage by the impedance of the trench gap in 32 trench gaps, where Poly-Si register is used [3-4]. In the case of high resistivity of 10-Gohm, breakdown voltage is not improved. However, in the case of 10-Mohm, it was improved drastically up to 6-kV. Figure 6 shows the results of sharing voltage at that condition. Shared voltages are almost uniform and the breakdown voltage is limited by BOX thickness. The references [3-4] include experimental results using the same structure. Here, the breakdown voltage of the trench area is calculated to be around 6-kV. However, Box thickness (2.5-μm) limits its breakdown voltage to around 4kV. It is necessary to use a thinner BOX in order to improve its breakdown voltage.

4. Conclusions
We analyzed the breakdown properties using the alterative impedance model against the traditional capacitance model and showed three approaches to improve its breakdown voltage and we showed decreasing the parallel impedance of trench gaps is effective technique for them.

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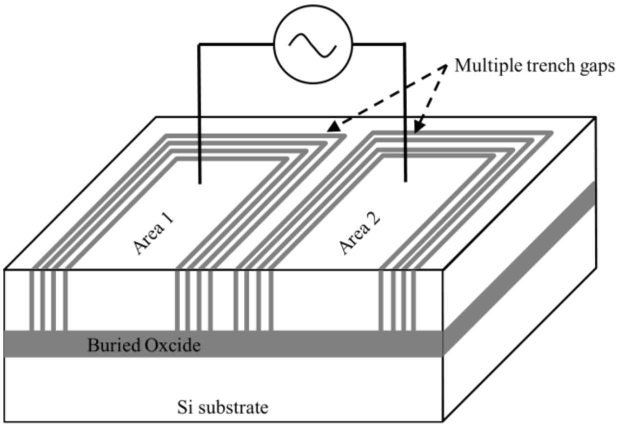

Figure1. Schematic chip view of multiple trench isolation [1-4].

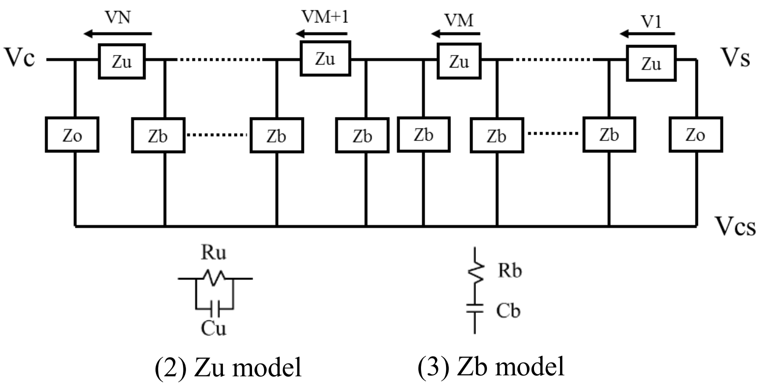

Figure2. Impedance model of multiple trench gaps.

Formula

$$\left(\sum_{i=1}^{N} V_i + V_s\right) = V_c. \quad (1)$$

$$V_k - V_{k-1} = \frac{Z_u}{Z_b}\left(\sum_{i=1}^{k-1} V_i + V_s - V_{cs}\right) \quad (2)$$

$$V_k - V_{k-1} = \frac{Z_u}{Z_b}\left(V_c - \sum_{i=N}^{k-1} V_i - V_{cs}\right) \quad (3)$$

$$\text{If } \frac{Z_u}{Z_b} \ll 1, \text{ then } V_i \fallingdotseq V_{i-1} \quad (i=2 \text{ to } N) \quad (4)$$

$$V_{tol} = (V_{break} / V_{imax}) \times (V_c - V_s) \quad (5)$$

Note
Vbreak: Breakdown voltage of trench gap
Vimax: Maximum shared voltage

Table 1 Device approach to improve breakdown voltage.

Approach		Details	Device Design
1	Increase voltage tolerance	Increase number of trench gaps	Increase number of trench gaps
2	Decrease impedance Zu	Increase capacitance Cu	Decrease trench width
		Decrease serial Resistance Ru	Add parallel resister to the trench gap
			Use spiral trench gap
3	Increase impedance Zb	Decrease capacitance Cb	Increase BOX thickness
			Decrease trench interval
		Increase serial Resistance Rb	Increase serial substrate resister

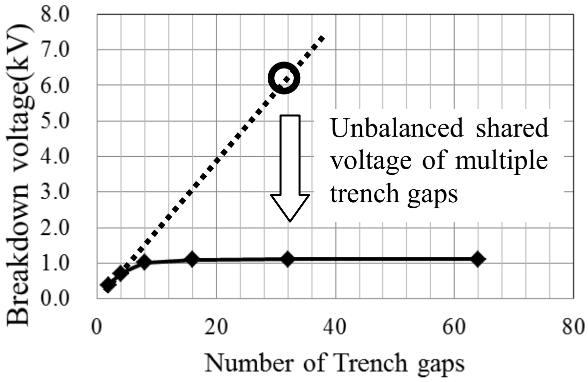

Figure 3. Dependence of breakdown voltage by number of trench gaps N.

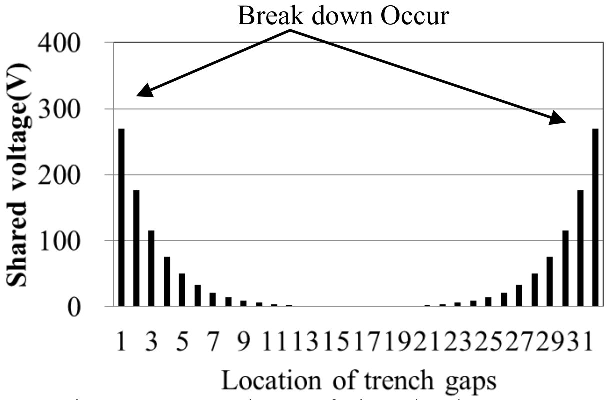

Figure 4. Dependence of Shared voltages on trench gap location.

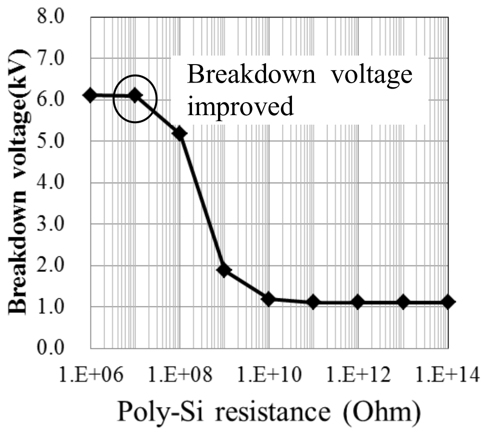

Figure 5. Dependence of breakdown voltage on parallel register Zu.

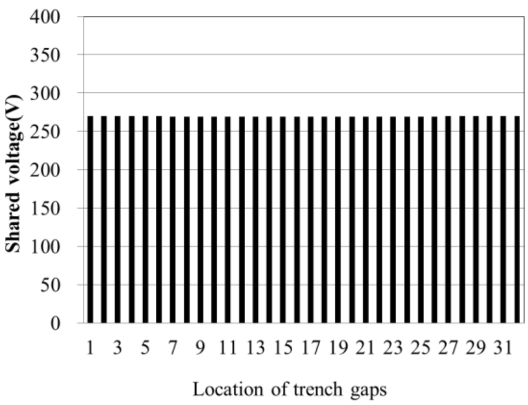

Figure 6. Dependence of shared voltage on trench gap location (10M ohm).