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Fully Ion Implanted DSA MOS IC

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Diffusion Self-Aligned(DSA)MOS ICs have received attention as sub-nanosecond and high-density logic elements[1]. DSA MOS FET has a sub-micron channel length achieved by the use of a double diffusion technique similar to bipolar ones and usual photolithographic method[2].

However, as the threshold voltage(Vth) of this FET is mainly determined by this double diffusion of P and N type impurities[3], these impurity profiles should be controlled precisely. This problem has been solved by using the fully ion implanted technique and theoretical analysis showed the good agreement with experimental results.

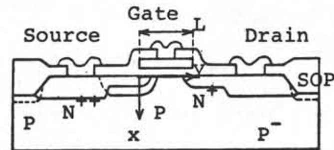

Fig.1 Cross sectional view of DSA MOS FET

The cross sectional diagram of this FET is shown in Fig.1. The features are summerized as follows, i) π-planar type, ii) Selective Oxidation Process (SOP) for field oxide, iii) poly-silicon for gate metal and iv) ion implantation for all impurity dopings.

Fig.2 shows the drain current (Id) vs. gate voltage (Vg) characteristics of the same size FETs with various kinds of P type impurity doping levels. In the low voltage region, Id is proportional to Vg^2 and should be controlled by P type diffused (enhancement) region[4]. The effective channel length is about 0.6μm in this case. In the high voltage region, the effective channel length of the transistor increases gradually with Vg by the contribution of the substrate (depletion) region.

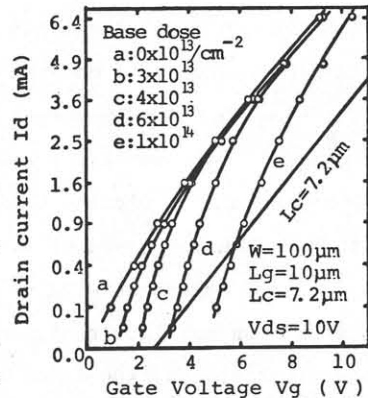

Fig.2 Id-Vg characteristics for various base doses.

Fig.3 shows the spreading resistance distribution closely connected to the impurity profiles of the implanted boron and phosphorus. As seen in this figure, the segregation effect into SiO_2 and emitter dip effect of boron, and the anomalous diffusion phenomenon of phosphorus are negligible because of the fully ion implanted and the N_2 drive-in processes. Therefore each

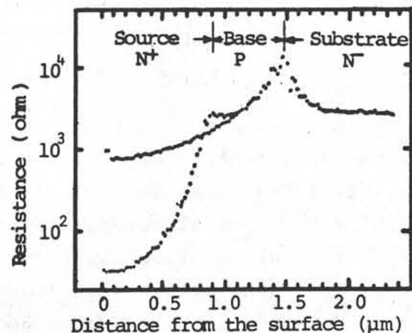

Fig.3 The spreading resistance distribution along vertical direction

lateral impurity profiles are approximately represented by the complementary error functions as mentioned by Kennedy et al.[5]. According to the first approximation, the Vth of this FET with N^+ Si gate is given by the maximum concentration of the P type diffused region and is represented as follows.

$$Vth = -\frac{Eg}{2} + \Phi_F - \frac{1}{C_0}\left(Qss - \sqrt{4\varepsilon_0 \varepsilon si\, q N_B \Phi_F} \right)$$

where

$$N_B = -\frac{N_D}{2\sqrt{\pi D_D t_D}} \operatorname{erfc}\left(\frac{y_0}{2\sqrt{D_D t_D}}\right) + \frac{N_A}{2\sqrt{\pi D_A t_A}} \operatorname{erfc}\left(\frac{y_0}{2\sqrt{D_A t_A}}\right) + N_{A0}$$

$$y_0 = \left[\left(\frac{1}{4 D_D t_D} - \frac{1}{4 D_A t_A}\right)^{-1} \ln\frac{N_D D_A t_A}{N_A D_D t_D} \right]^{\frac{1}{2}}$$

$$\Phi_F = \frac{kT}{q} \ln \frac{N_B}{n_i}$$

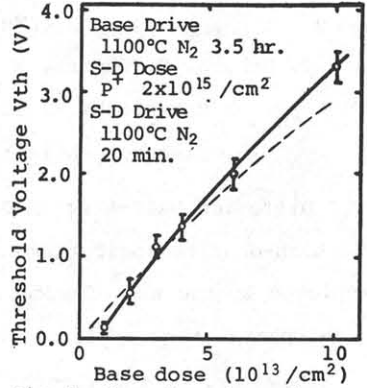

Fig.4 Base dose dependence of threshold voltage.

The Vth dependences on boron dose are shown in Fig.4. As the boron dose is controllable within ±5% accuracy, the deviation from the center value of Vth is kept within ±0.07V. Fig.5 shows the characteristics of Vth vs. Source-Drain diffusion time. As seen in this figure, the diffusion time dependence is still large because this process has been done at 1100°C. In order to make decreasing this dependence, lower diffusion temperature is useful. For over all process parameter fluctuation, the standard deviation of Vth has been kept within 0.15V around a designed value. In Fig.4 and Fig.5 , the calculated curves based on the above equations are also plotted. These curves give a good agreement with the experimental results. It becomes clear that the dominant control factor of Vth in the DSA MOS process is the control of the peak concentration, and the fully ion implanted and N_2 drive-in processes are very useful.

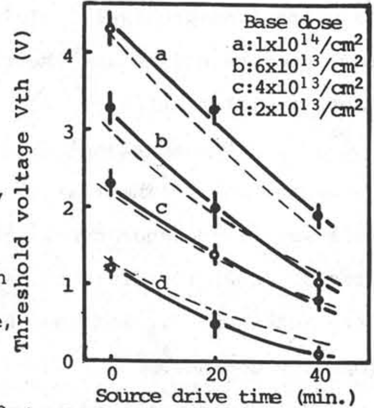

Fig.5 Souce drive time dependence of threshold voltage.

By using this technique, the 19-stage ring oscillator of the DSA MOS E-D inverter has been fabricated. The typical data of this one are as follows:

$$t_{pd} = 0.55 \text{ nsec}, \quad t_{pd} P_d = 0.055 \text{ pJ at } 2.7\text{ V},$$

$$t_{pd} = 0.36 \text{ nsec}, \quad t_{pd} P_d = 0.89 \text{ pJ at } 8.0\text{ V}.$$

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