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A Novel Conductance Measurement Technique for Profiling the Lateral LDD n-Doping Concentrations of Submicron MOS Devices

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This paper reports a simple I-V method for the first time to determine the *lateral* lightly-doped source/ drain (S/D) profiles (n^- region) of LDD n-MOSFET's. One interesting application is the direct observation of the reverse-short-channel effect (RSCE) [1]. It is observed that S/D n^- doping profile is channel length dependent if reverse short channel effect exists as a result of the interstitial imperfections caused by OED(Oxide Enhanced Diffusion) or S/D implant. Not only the lateral profile of long channel devices but also the short channel devices can be determined. It is an indispensible tool for the device drain engineering work in the current ULSI technology.

1. Introduction

In the device drain engineering, not only the S/D vertical profile but also its lateral profile is rather important for the submicron device design. For the S/D vertical profile, it can be characterized by SIMS or SRP measurement. To determine the lateral profile, a few [2-4] were reported based on the capacitance measurement method. However, all of these methods are for S/D n^+ profile only. None has been developed so far to determine the lateral n^- doping profile.

Recently, a so called Reserve-Short-Channel Effect (RSCE), has aroused much interests. This effect is commonly attributed to a lateral nonuniform doping profile along the channel. Poly-gate reoxidation [1], source/drain implant damage [5], and salicidation [6] in the submicron CMOS process have been identified as the cause for the above enhanced dopant diffusion. For the direct verification of the existing RSCE, various methods such as the decoupled C-V technique [7], the measured V_T-L curve [1] conventional C-V method [8], and charge pumping method [9] have been employed to show the existence of the non-uniform channel doping effects. In this work, we will for the first time propose a simple *I-V* method that allows direct determination of the lateral lightly-doped S/D (n^-) profiles for MOSFET's. Then, appropriate modification is carried out to characterize the boron-redistribution-induced RSCE in short-channel devices. Furthermore, applications to justify the S/D profile in drain engineering (e.g., LATID devices) were made. Finally, to show the validity and applicability of this method, the results have also been justified by using 2D simulation.

2. Experimental

Devices used in this study were fabricated using a poly-Si gate 0.6μm CMOS technology. The spacer width is 0.25μm. The split conditions for S/D n^- implant are Phosphorous 80kev, ($2x10^{13}$ cm^{-2}, $4x10^{13}$ cm^{-2}) with 0^o, 30^o, 45^o and 60^o tilt angle implants. The channel implant is BF_2 ($3.2x10^{12}$ cm^{-2}, 70kev). The S/D n^+ implant is As ($3x10^{15}cm^{-2}$, 80kev). All the devices have same drawn gate width 20μm but varying drawn gate lengths from 0.35μm to 20μm.

3. Paired *I-V* Method to Determine the Lateral S/D n^- Doping Profile

It has been reasonably agreed that L_{eff} can be defined as the distance between the two points where the gate-induced carrier density Q_n (in cm^{-2}) equals the doping profile $N_{S/D,2D}$ (in cm^{-2}) along the channel on S/D sides, as shown in Fig. 1. By applying the "paired V_{GS} method" as in [10], ΔL and extrinsic R_{ext} as the functions of V_{GS} can be determined and shown in Figs. 2 and 3. Here, R_{tot} is the total source-to-drain resistance. The correlation between doping $N_{S/D,2D}$ and Q_n can be expressed by eq. (1), where Q_n is the inversion carrier density at small V_{DS}. Also, by assuming the impurity doping profile being a Gaussian distribution with projected range ΔR_p, as shown in Fig.4(a), $N_{S/D,3D}$ can be related to $N_{S/D,2D}$ by eq.(2). As a consequence, the S/D profiles along the channel can be directly determined by diagrammatic manipulation as shown in Fig. 4(b) using the equations listed in Table 1. Results of the extracted S/D profiles for two different n^- dosages are shown in Fig. 5. We can see that LDD devices with higher n^- dosage exhibit a heavier concentration moving toward the center of the channel, as expected.

4. Boron-redistribution Effect from the Characterized S/D Doping Profiles

By observing the results from the R_{tot}-L_m curve shown in the inset of Fig.2, it can be seen that an anomalous behavior occurs, in which the values of R_{tot} deviate farther away from the fitting line due to the channel impurity nonuniformity as the device length shrinks. If we modify the previously-described method to determine ΔL and R_{ext} for short- and long-channel devices respectively, it will be shown that both the extracted ΔL and R_{ext} for long-channel devices (denoted by ΔL_l and $R_{ext,l}$) are larger than those for short-channel devices (denoted by ΔL_s and $R_{ext,s}$), while those (denoted

by ΔL_{all} and $R_{ext,all}$) fitted in the full channel length range (from .5μm to 20μm) give results much closer to ΔL_l ($R_{ext,l}$) compared to ΔL_s ($R_{ext,l}$), as demonstrated in Fig. 6. It means that as long as RSCE exists in short-channel devices, the extracted values are different from those of long-channel devices. Fig. 7 shows the corresponding n^- profiles from ΔL_s and ΔL_l versus V_G respectively. The n^- profile for short-channel devices moves back towards the outside of the active channel region, and also becomes more lightly-doped than that for long-channel devices. As noted earlier, this redistribution is a result of the nonuniformity in the channel doping profile as illustrated schematically in Fig. 8. In other words, the nonuniformity $\Delta N_B(x)$ in the channel profile (boron), that results in RSCE, will cause the moving of n^- profile boundaries for short- and long-channel devices. As shown in Fig. 6, this method can also provide the capability for direct investigation into the existence of RSCE from the comparison between ΔL_s and ΔL_l curves. If there is no RSCE existing in short-channel devices, these two curves should coincide together. In contrast, if RSCE becomes more significant, these two curves will deviate farther away from each other. Fig. 9 shows the simulated net doping profile along the channel for devices with and without OED [1] by SUPREM IV. It confirms the movement of the net profile as a result of boron redistribution.

5. Further Applications of the Present Method

For another practical application in the device drain engineering, S/D n^- profiles for the other LATID devices are also extracted and for a comparison in Fig. 10, in which larger tilt angle n^- implant has higher value of lateral doping and moves deeper into the channel. The lateral diffusion length (L_{n^-}) from the spacer edge to the drain junction can also be determined as given in Fig. 11 which provides important information for device drain eigineering work.

In summary, by using the conductance measurement technique in this paper, for the first time our studies show that: (1) the *lateral doping profile (along the channel)* of the lightly-doped n^- S/D region in LDD devices can be directly calculated, (2) the RSCE as a result of the process or channel implant-induced effect for the tested devices can be qualitatively and quantitatively determined, (3) the present method can be used as a monitor of the nonuniform lateral channel doping distribution in the state-of-the-art submicron VLSI/ULSI CMOS process and device design, and (4) it provides us an efficient tool for device drain engineering studies.

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References

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$$Q_n(V_{GS}) = \frac{C_{ox}}{q}(V_{GS} - V_{Th} - 0.5V_{DS}) = N_{S/D,2D} \quad (1)$$

$$N_{S/D,2D} = 2\sqrt{2}\Delta R_p N_{S/D,3D} \quad (2)$$

$$N_{S/D,3D} = k\cdot(V_{GS} - V_{Th} - 0.5V_{DS}) \quad (3)$$

where

$$k = \frac{C_{ox}}{2\sqrt{2}\Delta R_p q}$$

$$R_{ext} = R_{sp} + R_{n^-} + R_{n^+} + R_{co} \approx R_{sp} + R_{n^-} \quad (4)$$

Table 1 Equations for deriving the doping concentration from inversion layer charge density.

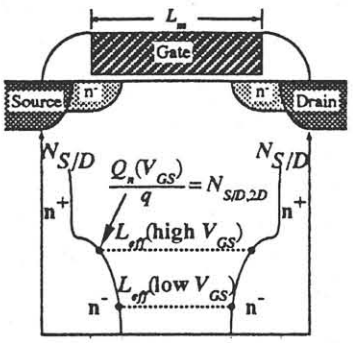

Fig. 1 A schematic carrier density plot along the channel and the definition of L_{eff} at low or high gate biases.

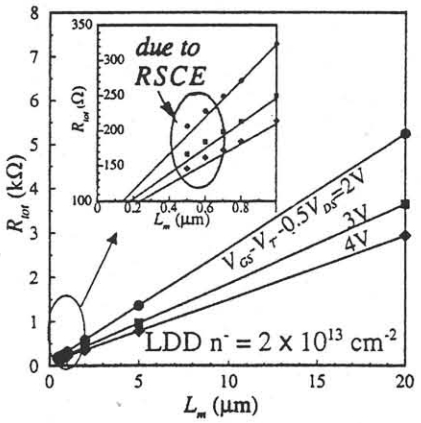

Fig. 2 Measured R_{tot}-L_m for LDD n-MOSFET's with n^-= 2x$10^{13}$$cm^{-2}$. Deviation of the measured data for short channel devices from the fitted line shows the observed RSCE.

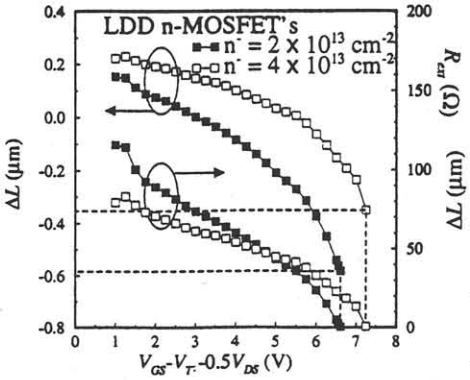

Fig. 3 Extracted ΔL and R_{ext} versus gate drive (V_{GS}-V_T-0.5V_{DS}) from long channel devices for two different n^- dosages.

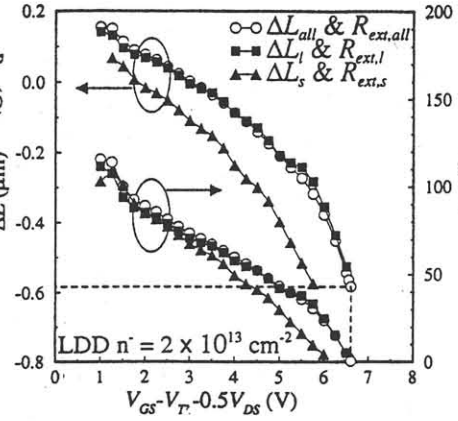

Fig. 6 ΔL and R_{ext} vs. (V_{GS} - V_T - 0.5V_{DS}) extracted for short-channel (L_m= 0.5μm) and long- channel (L_m= 20μm) devices.

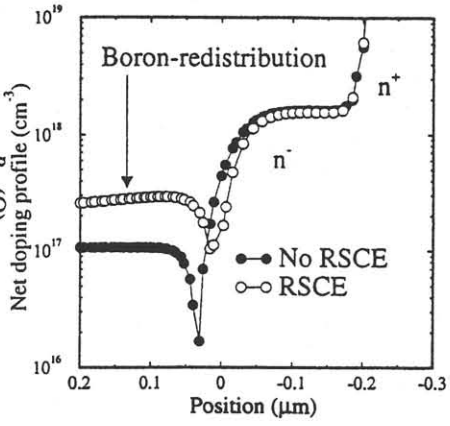

Fig.9 The change in the net doping profile simulated by SUPREM IV for devices with and without OED. Due to RSCE, the n^- profile moves back towards the outside of the active channel region.

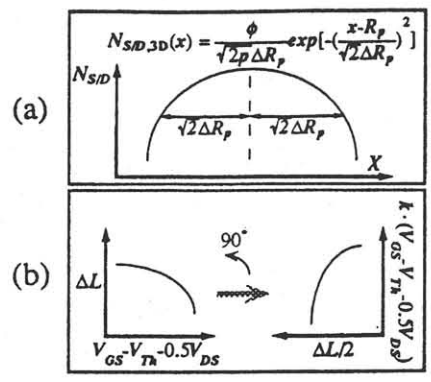

Fig. 4 Schematic illustration of the transformation from the ΔL versus gate drive into doping distribution along the channel.

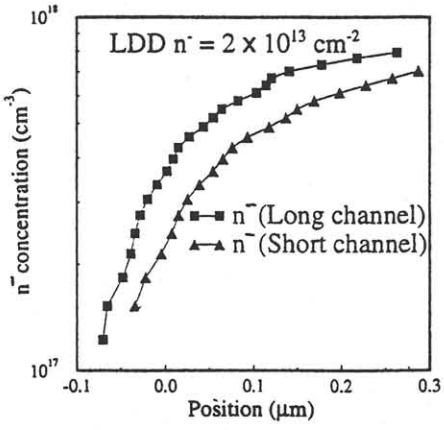

Fig.7 Extracted lateral n^- profiles for LDD MOSFET's with n^-= 2x10^{13} cm^{-2} for short-channel and long-channel devices.

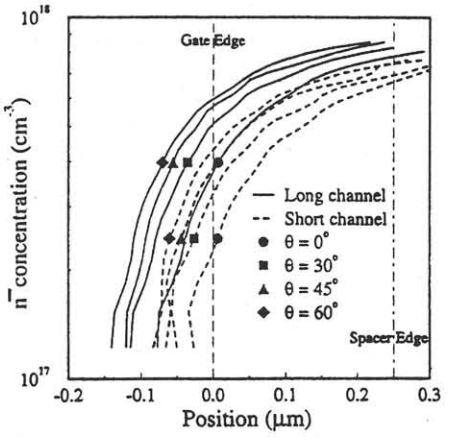

Fig. 10 Extracted lateral S/D doping profiles for LATID devices with n^- = 2x10^{13}cm^{-2}.

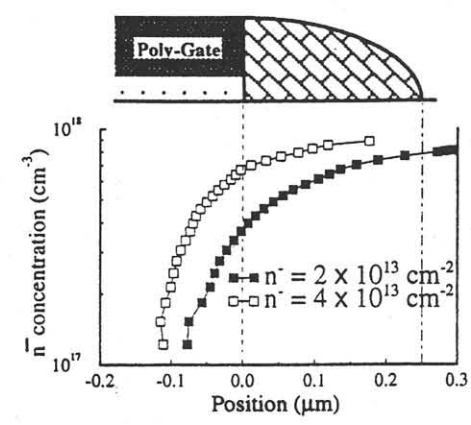

Fig. 5 Extracted lateral S/D n^- profiles for a long channel device L_m= 20μm with different n^- dosages from Fig. 3.

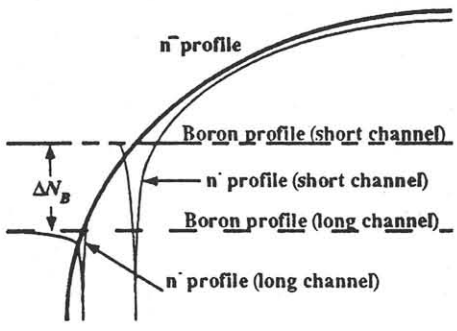

Fig.8 Qualitative description of the variations in channel doping profile due to RSCE. ΔN_B is the boron redistribution effect.

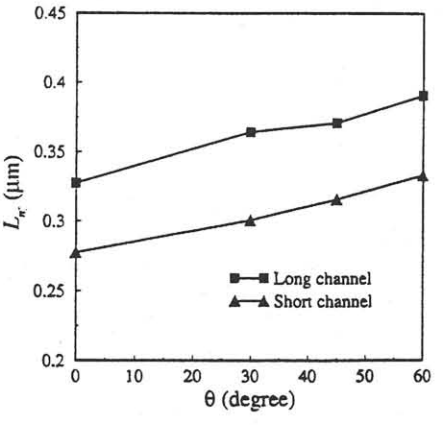

Fig. 11 Extracted L_{n^-} (spacer edge to the S/D junction) for various LATID devices.