Effect of Trench Depth and Trench Angle in a High Voltage Polyflanked-Superjunction MOSFET
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Introduction:
In recent times for the protection of global environment, green IT has been attracting attention as a way to achieve power savings. Super junction has arguably been the most creative and important concept in the field of power devices. The Superjunction (SJ) structure is an innovative breakthrough that is able to overcome the limitations of silicon [1]. Several fabrication technologies such as COOLMOS [1], STM [2] and sidewall doping technique have been implemented earlier to realize SJ devices. However, the complicated fabrication processes like unavoidable interdiffusion problem limits the production in case of COOLMOS and non-uniform doping profiles obtained because of recoil effects in case of sidewall doping technique. To address both the issues, polyflanked-Superjunction was proposed as an alternative process technology to realize SJ MOSFET [3]. During fabrication, due to the limitations in the etching equipments it is difficult to obtain the desired trench dimensions. This study with the help of TCAD simulations [4] gives a detailed explanation of the effects of different trench depth and trench angle along with the fabrication procedure of a Superjunction having a breakdown voltage over 800V with low specific on resistance less than 25 mohm-cm2.

Device Concept:
Superjunction structure enables a dramatically lower value of Ron.A, but it is difficult to maintain a high breakdown voltage until the charges are balanced between the n-type and p-type regions due to the charge compensation principle. [5]. SJ MOSFET needs a high aspect ratio of p and n columns. Fig.1 shows the process flow for a High Voltage Superjunction structure. An n-type layer with low resistivity is grown epitaxially on an n-type substrate with consideration given to the thickness of the buffer layer. Trenches are then formed in the epitaxy layer at a given angle and depth depending on the epitaxy thickness. In order to obtain an alternating n and p semiconductor stripes, trenches are then filled with boron-doped polysilicon. Final device after metallization is as shown in Fig.1 (d). It is not possible to achieve a desired trench dimensions with older etching equipments. Simulations are carried out to study the effects of irregularities observed while fabrication.

Results and Discussion:
Fig.2 represents a Superjunction structure, where “x” represents the variation in trench depths 35-55μm and θ represents the variation in trench angles 88°, 89° and 90° respectively. For a given 55μm epitaxy layer, increase in the depth of the trench results in an increase in the breakdown voltage, which is due to the increase in the depletion region of the device. Fig.3 represents the variation of breakdown voltage and on resistance with respect to the trench depths. The Breakdown voltage of a SJ MOSFET structure is directly related to the charge compensation principle. The excess charge present in the n-pillars must be counter balanced by the charge in the p-pillars. During on state, the on resistance of the device increases as the resistance offered by the drift region goes up as the trench depth is increased which can be analyzed from Fig.3. This can be illustrated from the graph that with gradual increase in the trench depth increases the on resistance of the device. In order to obtain the desired trade-off between Breakdown Voltage and specific on resistance, Fig.3 clearly emphasizes that the Superjunction structure with a trench depth of 45μm is the most suitable case with a high Breakdown Voltage of around 800V along with a low specific on resistance of 24mohm-cm2. The variation of breakdown voltage and on resistance with respect to the trench angle for a 45μm trench depth is as shown in Fig.4. During fabrication, the etching of deep trench may not always yield results of the desired dimensions; there may be some variations in the trench angles. Slight variation in the etching of the trench will in turn lead to an excess of concentration level of either n-pillar or p-pillar which will ultimately cause charge imbalance in the device. Hence in this structure, trench angle is also a major factor to be considered for optimum BV and Ron-A. Fig.4 distinctly indicates that an ideal trench angle yields better electrical performances. Fig.5 portrays the electrical characteristics of a Superjunction with a trench angle of 90º and trench depth of 45μm. It can be observed that with the increase in boron concentration the breakdown voltage gradually increases and then it starts decreasing due to charge balance principle, while the on resistance keeps on increasing with the increase in boron concentration. Fig.6 shows the electric field plot for a Superjunction device with trench angle of 90º and trench depth of 45 μm.

References:
Fig. 1: Process flow for a PF-SJ

Fig. 2: PF-SJ structure with varying trench depth and trench angle

Fig. 3: Breakdown voltage and Ron with respect to trench depth

Fig. 4: Breakdown voltage and Ron with respect to trench angle

Fig. 5: Breakdown voltage and Ron for different Boron concentrations

Fig. 6: Electric Field