700volt MEMS SUPERJUNCTION MOSFETS
for
Green Energy APPLICATIONS.

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Introduction

In many electronics applications a load has to be fed with a current at variable frequency and amplitude, with energy supplied directly from the mains voltage. If the load must be supplied from the wall socket mains, the mains voltage is rectified, filtered and converted from AC to DC. The load is then connected to a switch topology that can be realized by one or more power devices, that have the function of controlling the current and hence the power into the load. Such applications, in which the load is directly fed by rectified mains voltage are called off-line applications. Active Power Factor Correction for electronic LED Lighting, Electric Motor Variable Speed Drives, Plasma Display Panels, are just a few of the applications that benefit from off-line AC to DC Power conversion. Figure 1.0 shows the voltage range of these off-line AC/DC applications for Power MOSFETS within the scope of Power MOSFET applications. The Superjunction technology developed at IceMOS enables off-line AC/DC power conversion to be supplied to the market at reduced size, improved efficiency and lower cost over traditional MOSFETs.

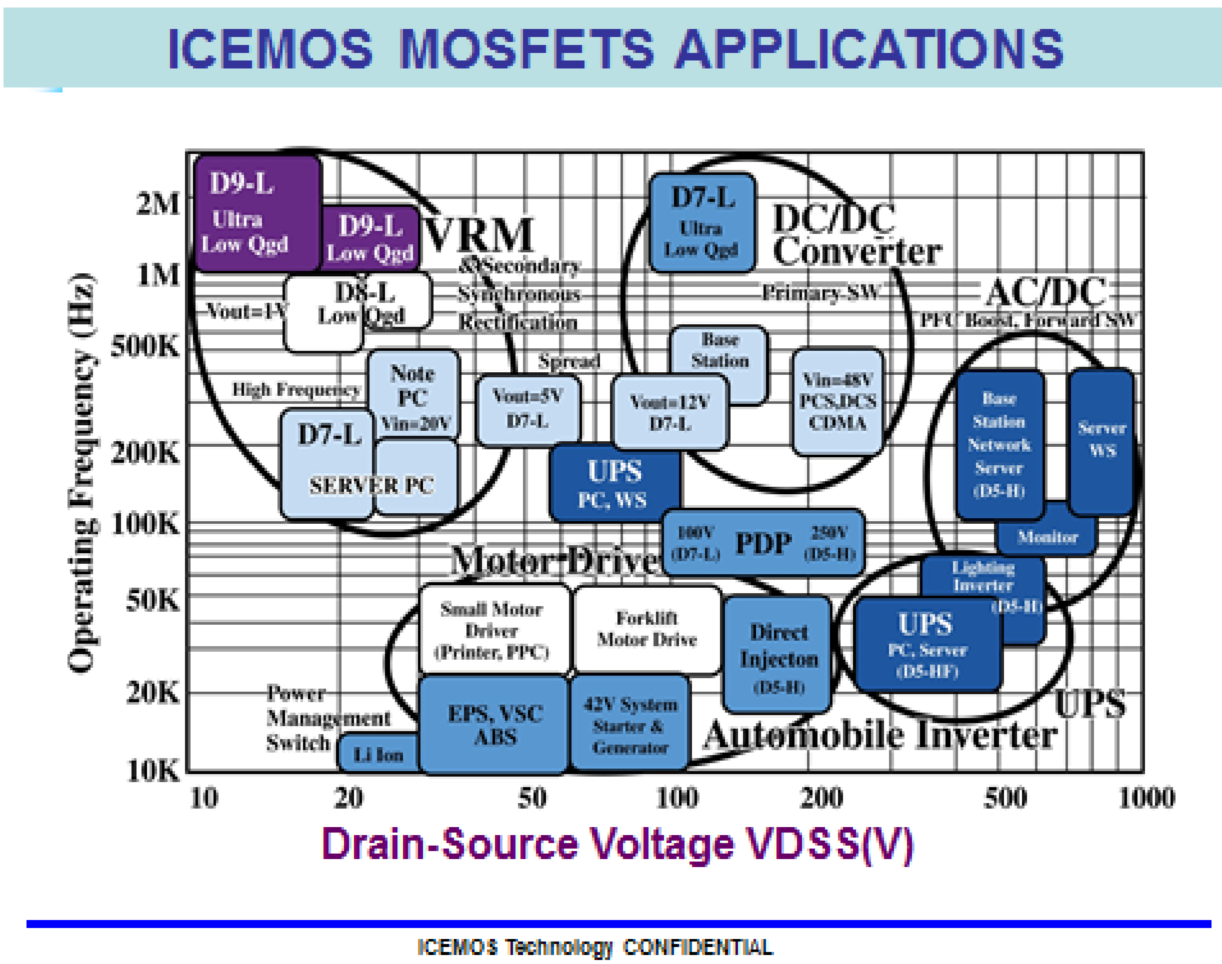

Fig.1 Applications for IceMOS MEMS SJ MOSFET

Recently a revolutionary device concept termed MEMS MOSFET transistor has emerged to break through the theoretical limits of conventional silicon high-voltage power devices. The concept is also known as the *multi-RESURF* or ICEMOS ™ in commercial applications. This super-junction transistor is based on the concept of charge compensation across a PN junction made of alternatively stacked, heavily doped N and P regions (pillars or columns) and relaxation of the peak electric field by diverging into multiple dimensions. Figure 2 compares the device structures and electric fields distributions of a one-dimensional PN junction and a multi-dimensional super junction. For the same doping profiles,

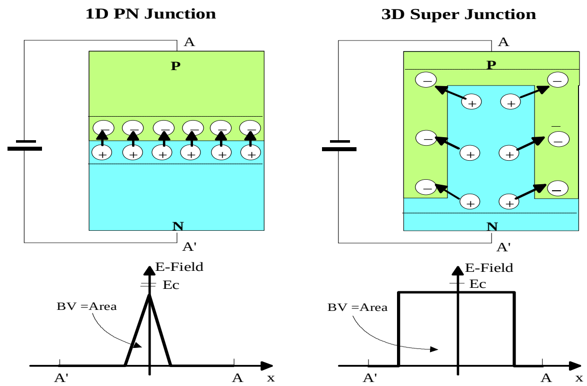

Fig.2 Device structure of 1D and 3D MOSFETs

the electric field across the super junction is much lower than that in the conventional PN junction. Therefore, a much higher breakdown voltage is achieved in a super-junction transistor. In other words, a super-junction transistor can offer a high breakdown voltage and a low on-resistance (due to the heavy doping in the N and P pillars) all at the same time. 600-volt power MOSFETs based on the SJ concept have demonstrated as much as a 5X reduction in on-resistance while theoretical analysis has indicated that up to a 100X reduction could be achieved.

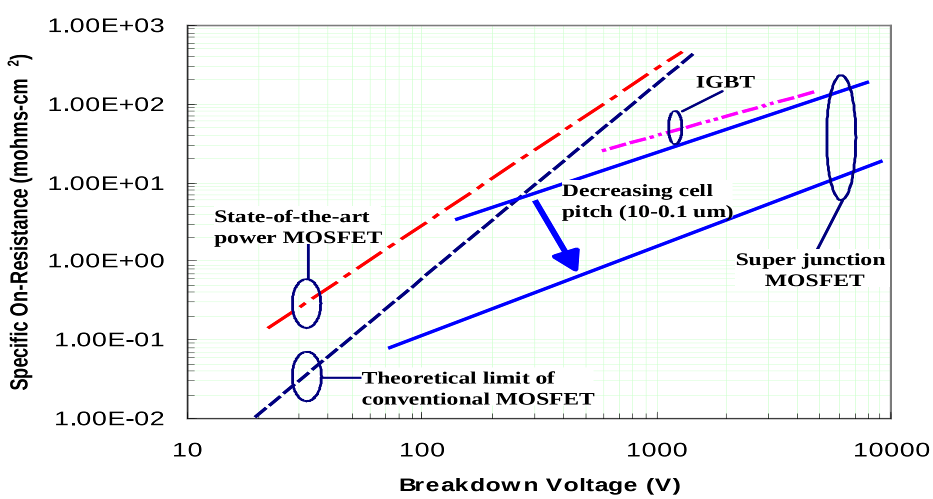

Fig.3 Specific on resistance as a function of breakdown voltage for conventional MOSFET, SJ-MOSFET, and IGBT.

Figure 3 demonstrates the specific on-resistance as a function of the breakdown voltage of the conventional MOSFET, the super-junction MOSFET, and the IGBT, based on the published literatures and our own analysis. It is clearly shown that:

The super-junction concept, while elegant and amazingly simple in principle, is extremely difficult and challenging to realize in practice. This is due to the requirement of forming three-dimensional device structures with a very high aspect ratio. For example, N or P pillars of several tens of micrometers in depth and a few micrometers in width are required to achieve a breakdown voltage of 300-1000 volts.

MEMS and DMOS Design is the Core Technology of IceMOS MEMS SJ MOSFET

MEMS applications require high aspect ratio silicon structures with good feature size control, good etch uniformity, and high etch rates for efficient production and commercialization. Recently the deep ion reactive etch (DRIE) technique, also known as inductively coupled plasma (ICP) or time multiplexed deep etch (TMDE), has been widely used for such purposes Figure 4. The DRIE technique, developed and licensed by Robert Bosch GmbH.

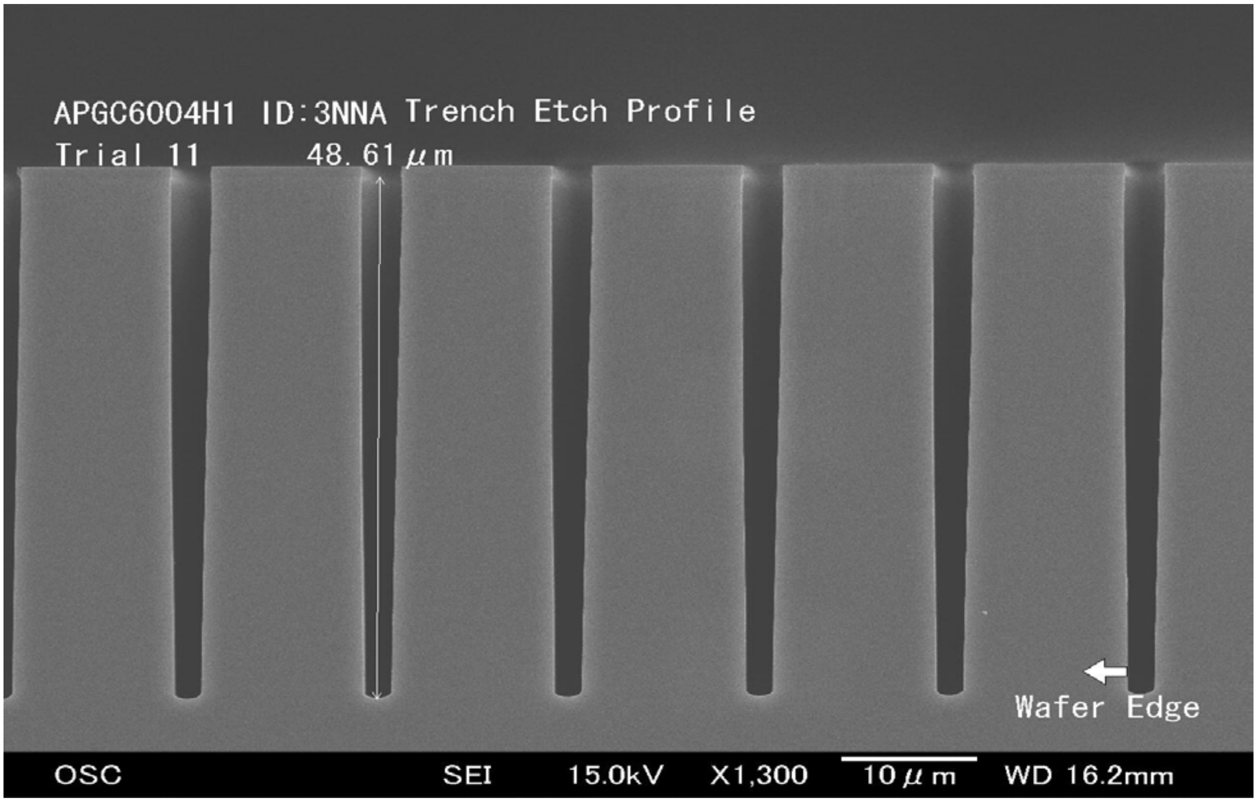

Fig 4. DRIE TRENCH PROFILES

The years and millions of dollars invested in the IceMOS MEMS SUPERJUNCTION TECHNOLOGY has resulted in innovative technologies designed performance and centered for achieving significant reduction in conduction loss, switching loss, and fabrication cost over the conventional DMOS technologies. To achieve the maximum breakdown voltage in a SJ structure, the charge (Q) in the P and N pillars must be exactly balanced and chosen such that the pillars are completely depleted before breakdown occurs (i.e. $Q < \varepsilon_{Si} E_c/q$). This ensures that the electric field profile is rectangular (instead of triangular as in the conventional MOSFET case) and that the breakdown is dependent only on the epi-layer thickness and independent of the doping concentration. Assuming a perfectly flat electric field profile, the breakdown voltage BV, charge Q, and specific on-resistance R_{on} are simply given by

$$BV = E_c t_{epi}$$

$$Q = \frac{N_d \cdot W}{2} = \frac{\varepsilon_{si} E_c}{2}$$

$$R_{on} = \frac{t_{epi}}{q\mu_n N_d} = \frac{W \cdot BV}{2q\mu_n E_C Q} = \frac{W \cdot BV}{2\mu_n E_C{}^2}$$

where E_c is the critical electric field strength, t_{epi} is the thickness of the epitaxial layer (height of the pillars), N_d is the doping concentration of the N pillars, W is the cell pitch, and μ_n is electron mobility. It is clearly shown in Figure 5 that the relation between the BV and R_{on} of the SJ MOSFET is linear, unlike the power law relationship of the conventional MOSFET.

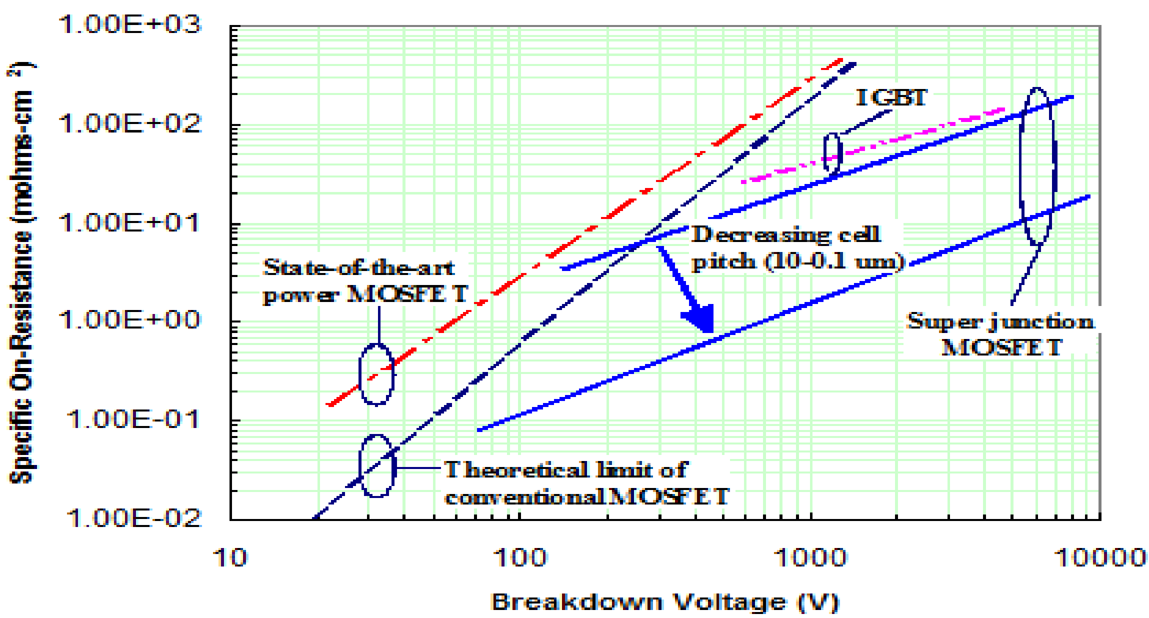

Fig 5. The IceMOS MEMS SUPERJUNCTION MOSFET delivers a 5Xreduction in Rdson over convention MOSFETs

The LED LIGHT BULB is a good example that can benefit from the IceMOS MEMS SJ MOSFET. LED bulbs saves energy because they require less power input for the same light output. Figure 6 (Substantial Energy Conservation benefit.)

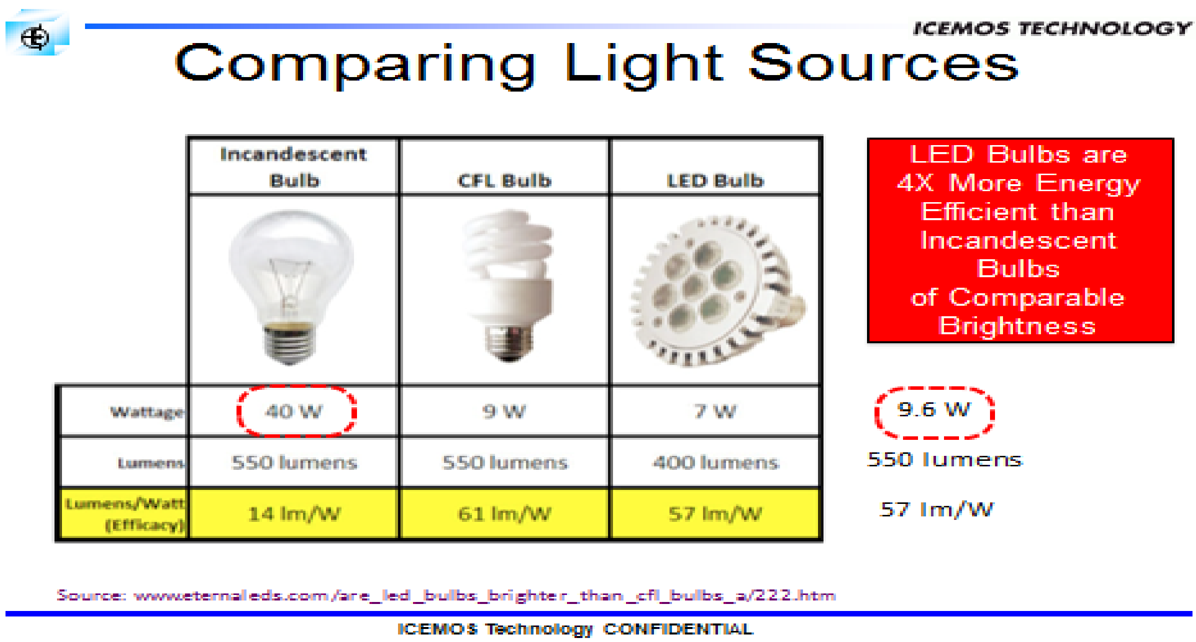

Fig 6. Comparison of Light Sources for General Lighting Market

Power MOSFETs are arguably the most critical enabling components in high efficiency, high density Power Systems. Conventional Planar DMOS technology does not meet the low Rdson performance for improved Green Energy Applications. IceMOS, has introduced an alternative power MOSFET technology, including the world's first power MEMS SJ MOSFET with 5X REDUCTION in ON resistance over conventional High Voltage MOSFETs. These MEMS SJ MOSFETs with a voltage rating up to 700V, offer BVDSS and Rdson performance superior to the best-in-class Planar DMOS and Multiple Epi Superjunction MOSFETs [0], and are successfully designed into the current generation of LED based applications