COMFET Power Devices Speeding Up

Structural Improvements Reduce Fall Times Down To One-Half Microsecond

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Until recently, COMFETs (conduction-modulated FETs), a relatively new class of power-switching semiconductors, have offered the capabilities of conventional MOSFETs with an enhanced conductivity at higher voltages with the penalty of far slower switching speeds.

But now, a new high-speed COMFET, recently developed by RCA, has achieved fall times as low as 0.5 ns. While still not as fast as MOSFETs, these high-speed COMFETs are an attractive alternative to MOSFET bipolar, and other devices for a variety of high-voltage, high-current, switching applications including automobile ignition, power supply, and motor-control circuits. In addition, the high-speed COMFET achieves its rapid fall time without sacrificing the low on-resistance, reduced conduction losses, high input impedance and other performance advantages that are characteristic of the COMFET family of devices.

MOSFET Drawbacks

MOSFETs have become increasingly popular in discrete power applications, primarily because of their high input impedance, rapid switching times, and low on-resistance.

Unfortunately, the resistance of MOSFETs is nearly fixed at the value of drain-source voltage capability—on-resistance increases, on-resistance increases even more. For this reason, MOSFETs are limited in their performance at high voltages. Their greatest strength is usually in applications below 200 V.

COMFETs, a relatively new category of power semiconductors, offer the high input impedance and simplified drive circuitry of MOSFETs yet have lower conductive losses. In switching speed, they are competitive with bipolar transistors. In size and cost, they exceed bipolar capability. By combining the best of both MOSFET and bipolar technology in a single product, and cutting the die size and cost, COMFETs offer a high-performance, cost-effective alternative to both MOSFETs and bipolar devices in numerous high-voltage applications.

The high impedance of COMFETs, which is as same as that of MOSFETs but at approximately one-tenth the on-resistance, is due to the device's structure. This structure is remarkably similar to a standard n-channel MOSFET, except that the n+ epilayer region is grown on a p+ substrate instead of an n+ substrate. The heavily doped p+ region in the center of each unit cell, combined with the aluminum metal contact shorting the n+ and p+ regions, provides shunting resistance, which limits the switching speed and maintains gate control within a large range of anode voltages and currents.

In high-voltage FETs, the epilayer region accounts for between 80 and 90 percent of the total on-resistance. It follows that by lowering the epilayer region resistance, the total resistance can be significantly reduced.

In the COMFET, this is accomplished through a technique called "conductivity modulation." In conductivity modulation, minority carriers are injected into the n+ epilayer region from the p+ substrate. As current flows from drain to source, it hits the p- n+ junction, causing carriers to flow into the n+ region. The effect is enhanced conductivity and on-resistance reduction that is approximately an order of magnitude lower than conventional MOSFETs. This, in turn, permits better use of silicon to reduce die size and drive the cost down. Typical on-resistance values for an RCA COMFET are on the order of 0.2 Ω.

Moreover, the COMFET's on-resistance does not increase with forward voltage, as it would in a standard MOSFET. Thus, at a blocking voltage of 1,000 V, the COMFET's on-resistance may be as much as 50 times lower than the resistance of a comparable MOSFET.

However, the COMFET's lower on-resistance, higher conductivity and lower power dissipation—advantages over MOSFETs—are partially offset by the COMFET's slower switching speed—from on to off state.

Reduced Fall Time

In a MOSFET, fall times are in the tens of nanosecond range, because the flow of majority carriers stops Instantly as the voltage is switched off. But in COMFETs, the conductive minority carriers present in the epilayer region are still there when the voltage is removed. These carriers must decay by recombinating within the structure, and until they are neutralized, the COMFET cannot reach its true off state. And because recombinaction is relatively slow, the COMFETs are inherently slower switching devices than MOSFETs.

One way to increase COMFET switching speed is the introduction of "recombination centers" into the epilayer region. These are sites at which minority carriers can recombinations and decay quickly. Recombination centers can be added to the n+ layer using a variety of techniques including high-energy electron, proton, and neutron irradiation, as well as heavy-metal doping.

By adding recombination centers, RCA has been able to manufacture COMFETs with fall times in the range of 1 µs at room temperature.

However, even at this level, the COMFET is not fast enough to handle the frequencies typical of many high-voltage power applications. As a result, a new "high-speed COMFET" with fall times rated at 0.5 µs at 10°C.

The new high-speed COMFET is similar to previous RCA COMFETs, except that a thin micrometer layer of n+ silicon is added to the epilayer structure of the n- region and the p+ substrate. This n+ layer lowers the emitter injection efficiency of the pop transistor, so that fewer minority carriers are present when the voltage is turned off. The result is faster fall times while increasing the capability to handle higher current. And this is achieved with no significant increase in on-resistance.

This new high-speed COMFET represents the state of the art in conductivity-modulated FET technology. Like MOSFETs, the input in voltage-controlled. And very little drive power is required to moderate switching frequencies in the off state.

High-Voltage Applications

Because they offer a blend of both MOSFET and bipolar technology, COMFETs can be used to replace these devices in many circuit designs. COMFETs are best suited to high-voltage applications above 200 V; their lower on-resistance makes them more desirable than standard MOSFETs. At lower voltages, where the resistive advantages of COMFETs are not as great, MOSFETs may be preferred for their superior switching speeds. Today's COMFET is inherently slow in fall time, which limits its use in high-frequency applications greater than 30 kHz. New technoloogies have been introduced to improve that performance.

One major application of COMFETs is in switching power supplies, where COMFETs provide MOSFET capability at lower cost and with less power dissipation. But the need for switching speed may limit its use in power supplies using high frequencies.

In braking applications, COMFETs can be used to electronically switch the voltage on the stator windings. In larger motors, large MOSFETs...
are often used to reduce power dissipation and meet the heat-handling limitations of the package. By switching to COMPETs, which have an on-state voltage drop that is, for all practical purposes, independent of temperature, designers can achieve significantly lower power (and heat) dissipation. Also, die size is smaller and costs are lower.

COMPETs can be designed to replace bipolar transistors in automobile ignition systems. With bipolar switchers, two-thirds of the power dissipation in the control IC is the result of the need to drive the base current of the ignition output transistor. The high-input impedance of the COMPET eliminates this base-current drive dissipation.

Additionally, it can be a cost-effective alternative to the MOSFET for many other applications in the 200- to 500-V, 1- to 20-A range. These include ballasting for lamps, programmable controllers, ultrasonic transducers, solid-state relays, off-main switching power supplies, ac motor control circuitry, dc-to-dc converters and military electronics.

COMPET R&D Advancements

Research and development efforts by RCA and others like GE and Motorola are broadening the product matrix and expanding the capabilities of COMPET technology. The high-speed COMPET is only the first of many new COMPET devices that will be introduced on a commercial basis by the end of the decade.

In addition to n-channel COMPETs, RCA is also working on a p-channel COMPET. Laboratory samples indicate that the p-channel COMPET will use silicon more efficiently than its MOSFET counterpart.

Current ratings of COMPETs will be extended from the present 10 A to anywhere from a few amperes to 50 A or more.

Voltage ratings of 1,000 V have been demonstrated in the laboratory, with 2,000 V being feasible. And in addition, future COMPETs will also block voltages in both directions, not just the forward direction.

RCA recently announced an L1 FET (logic-level MOSFET) that can be operated from a 5-V power supply. A logic-level COMPET, also capable of being driven by 5 V, is also in the works.

New COMPETs will offer improved freedom from latchup, faster switching speeds and lower voltage drops. Fall times below 0.5 μs will allow COMPET power converters to function at 100 kHz vs. today’s upper limit of 20 to 30 kHz.

Future products will include JEDEC-registered and high-reliability COMPETs, plus radiation-hardened COMPETs with gamma-dose rate survival approaching 10^9 rads per second and total gamma dose up to a megarad.

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