COMFET Power Devices Speeding Up

Structural Improvements Reduce Fall Times Down To One-Half Microsecond

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Until recently, COMFETs (conductivity-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 µs. 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 circuitry. In addition, the high-speed COMFET achieves its rapid fall time without sacrificing the low on-resistance, reduced conductive losses, high input impedance and other performance advantages that are characteristic of the COMFET family of devices.

MOSFET Drawbacks

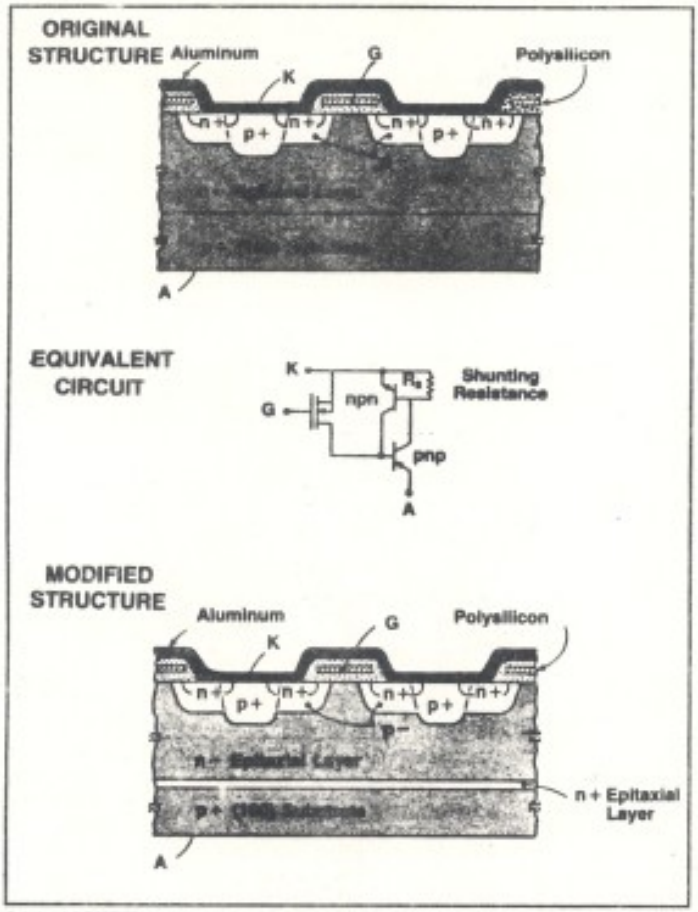
MOSFETs have become increasingly popular in discrete power applications, primarily because of their high input impedance, rapid switching times and low on-resistance.

Unfortunately, the resistance of MOSFETs is nearly a cubic function of drain-source voltage capability—as voltage increases, on-resistance increases even more. For this reason, MOSFETs are limited in their performance at higher 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 driver 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 die size and cost, COMFETs offer a high-performance, cost-effective alternative to both MOS and bipolar devices in numerous high-voltage applications.

The high impedance of COMFETs, which is 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^- epitaxial layer 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 contact shorting the n+ and p+ regions, provides shunting resistance, which helps prevent latching and maintain gate control within a large range of anode voltages and currents.

In high-voltage FETs, the epitaxial



Original COMFET structure (a) and equivalent circuit (b). Structure has been modified (c) to decrease fall time. An n+ epitaxial layer has been added between substrate and n− epitaxial layer to lower injection efficiency of pnp, so fewer minority carriers are present when voltage is turned off.

region accounts for between 80 and 90 percent of the total on-resistance. It follows that by lowering the epitaxial 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^- epitaxial region from the p substrate. (As current flows from drain to source, it hits the p-n junction, causing these carriers to flow into the n^- region.) The effect is enhanced conductivity and an on-state resistance 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.

Furthermore, 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-size-die 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 epitaxial region are still there when the voltage is removed. These carriers must decay by recombining within the structure, and until they are neutralized, the COMFET cannot reach its true off state. And because recombination 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 epitaxial region. These are sites at which minority carriers can recombine 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 speed is still not fast enough to handle the frequencies typical of many high-voltage power applications. As a result, RCA has developed a new "high-speed COMFET" with fall times rated at 0.5 µs at 100°C.

The new high-speed COMFET is similar to previous RCA COMFETs, except that a thin 10-micron layer of n+ silicon has been added to the epitaxial structure between the n^- region and the p+ substrate. This n+ layer lowers the emitter injection efficiency of the pnp 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, its input is voltage-controlled. And very little drive power is required up to moderate switching frequencies. It remains under gate control when operated within its specified voltage and current ratings.

Besides reducing the fall time, the thin n+ layer built into the new high-speed COMFETs provides the added benefit of raising latching currents two to three times over previous devices. Latching currents in the new high-speed 10-A COMFET are approximately 50 A, even with rapid gate turn-off. Therefore, these COMFETs can safely be used in higher current applications without the fear of latchup, which occurs due to the parasitic thyristor inherent in the COMFET structure.

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 so 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 technologies are being 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, COMFET's switching speed may limit its use in power supplies using high frequencies.

In brushless dc motors, 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 COMFETs, 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.

COMFETs can be designed to replace bipolar transistors in automobile ignition systems. With bipolar switches, 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 COMFET 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.

COMFET R&D Advancements

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

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

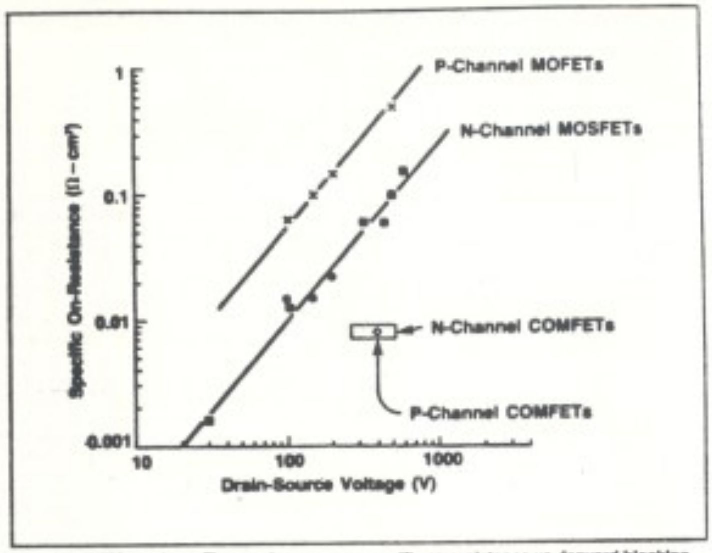
Current ratings of COMFETs will be extended from the present 10 A to anywhere from a few amperes to 50 A or more.

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

RCA recently announced an L^2 FET (logic-level MOSFET) that can be operated froma a 5-V power supply. A logic-level COMFET, also capable of being driven by 5 V, is also in the works.

New COMFETs will offer improved freedom from latchup, faster switching speeds and lower forward voltage drops. Fall times below 0.5 μs will allow COMFET 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 COMFETs, plus radiation-hardened COMFETs with gamma-dose rate survival approaching 10^{11} rads per second and total gamma dose up to a megarad.



How COMFETS stack up. The graph compares specific on-resistance vs. forward blocking voltage for p-channel and n-channel MOSFETs and COMFET power devices.

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