Intelligent Doping Leads to Success

Switched power supplies are everywhere today; it is the only technology capable of delivering high efficiency. Power factor correction supposedly can keep sine wave distortion and noise low in the power grid, but also creates additional power losses. New, specially designed Silicon diodes can reduce the costs for such circuitry easily. **Wolf-Dieter Roth, HY-LINE Power Components, Unterhaching, Germany**

Diodes are the first semiconductor component being implemented in industrial processes starting with the galena crystal detectors of the early radio industry. Then came selenium rectifiers, germanium diodes and transistors, silicon components from diodes up to microprocessors, Gallium Arsenide (GaAs) amplifiers and light emitting diodes, Gallium Nitride (GaN) and silicon carbide (SiC) semiconductors and finally Schottky barrier semiconductors, coming up with a barrier between semiconductor and metal, thus somehow closing the circle back to the crystal detector.

New semiconductor materials offer exciting physical characteristics, which make new devices like the blue LED possible. But new materials also implement a new learning curve in production, leading to high prices and higher failure rates when production of a new semiconductor starts. Sometimes later as well: GaAs semiconductor components never really became mass market - the material is still too expensive and difficult to process compared to silicon.

An interesting strategy thus is to improve today's standard semiconductor processes with clever constructions: Gigahertz amplifiers, which once could only be realised in GaAs technology, are built on a standard silicon wafer nowadays. Similarly, attributes once only associated to SiC components may now also be realised in plain silicon semiconductors, which is not only saving money, but also offers more robustness. An example for this are the Qspeed power factor correction diodes offered by HY-LINE Power Components (see Figure 1).

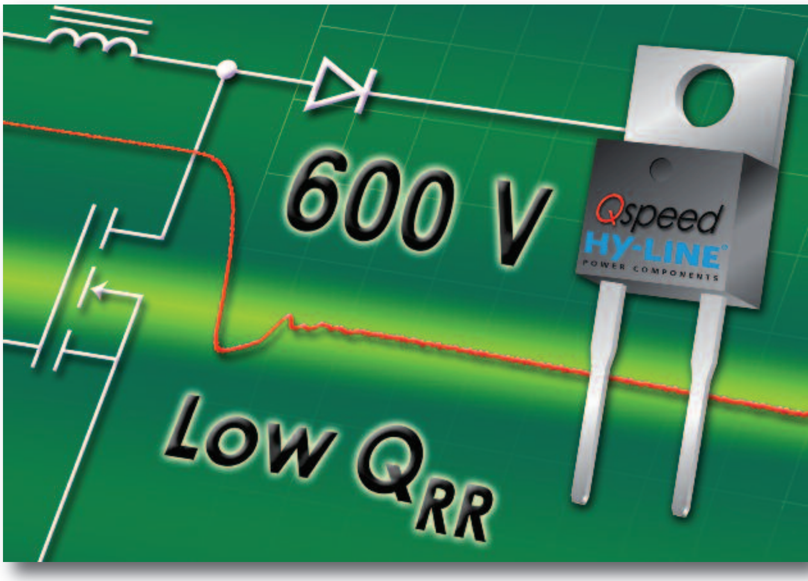

Figure 1: Qspeed-HY-LINE PFC diodes are optimised for PFC applications

High efficiency and poor power factor

Switched mode power supplies (SMPS) are a big step-up from the classical setup of a 50/60 cycles transformer, rectifier and linear regulator. They offer higher efficiency, smaller volume and weight, plus smaller idle losses. However, a problem for the power grid remains: their output is gained from inverting, transforming and rectifying of a DC voltage that is derived directly via diodes from the mains, without the damping and linearising effect of a conventional mains transformer being put in-between.

Instead of the continuous draw of a resistive load or the phase shifted, but still continuous draw from capacitive or inductive loads, a rectifier with a following load capacitor will cause a pulse draw. The mains will only be loaded at the voltage peak to recharge the capacitor - power factor is low. The result: In offices with a lot of personal computers or in computer centres the sine wave of the mains voltage will be cut off thus leading to harmonics in the mains; also the pulse currents will lead to higher wire losses. Finally the missing sine wave peaks will result in lower voltage

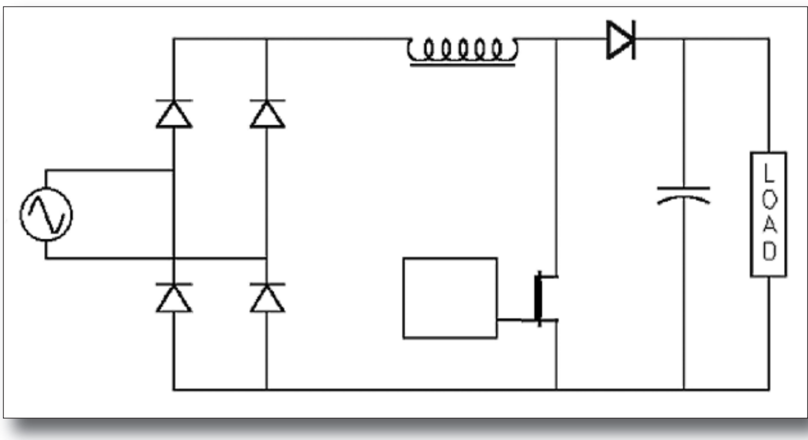

Figure 2: Block diagram of the front rectifier of a switched power supply with PFC circuitry

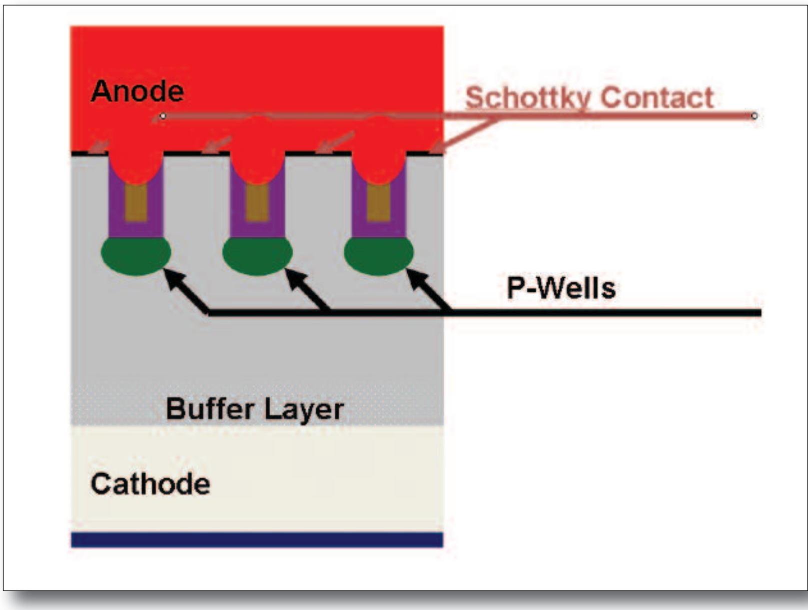

Figure 3: Internal structure of a Qspeed diode

at the charge capacitors in the power supplies.

Power factor correction (PFC) circuits (Figure 2) normally use an additional step-up converter (boost) as a front end, which delivers current to rectifier and charge the capacitor continuously through the whole current phase instead of only at the peak. Thus problems with harmonics and line overload will be reduced, as long as the PFC circuit does not create any harmonics itself, but efficiency will still suffer slightly, even though the mains is used more efficiently, due to the fact that now a second converter is in use. It is important to make the PFC converter as efficient as possible to not devaluate the power factor correction.

One key component next to the inductor is the diode used in the PFC circuit: it has to switch fast, but not too rough, and must have a low reverse recovery charge Q_{RR}. Often SiC semiconductors are used for this, but their Q_{RR} is sub-optimal.

Speed is not always sufficient

Qspeed's diodes (Figure 3) for PFC applications are offering forward voltage, reverse voltage and -current, plus speed similar to much more expensive SiC diodes, for a price only slightly above that of ordinary silicon high speed (ultra fast) diodes.

These diodes have far less EMI problems compared to standard hard-switching platinum-doped "ultra fast" diodes due to "soft recovery", they are an excellent choice for PFC applications operating directly on mains power, where all kinds of electromagnetic interference due to hard switching slopes can immediately spread into the grid.

Qspeed diodes offer up to 5% more efficiency compared to conventional silicon "ultra fast" diodes, reduce MOSFET temperature of 5 to 20K due to their lower reverse recovery charge and deliver better EMI performance. If those advantages are used to use the next smaller MOSFET size, overall costs will stay the same or even drop while efficiency is still higher due to the fact of easier filtering. The efficiency of a power supply using PFC rises up to almost a whole percent point if Qspeed diodes are used (Figure 4).

Robust CMOS wafer technology

Currently, Qspeed's diodes are available up to 600V / 20A or 300V / 30A and also as a dual unit. However, it is not a good idea to choose a diode of larger size than the circuit really demands. Diodes with higher voltage or current reading will also have a higher charge that has to be dissipated when reversing polarity (reverse recovery charge). Thus efficiency would drop. Also, bigger diodes would of course cost more. As a rule of thumb for choosing the right diode the manufacturer recommends around 1A per 100W of the power supply rating.

Some characteristics of silicon diodes will work against each other. If the semiconductor wafers are heated longer when doping them, foreign atoms may diffuse stronger into the material, thus lowering the forward voltage V_F but rising Q_{RR}. Qspeed diodes are optimised for low Q_{RR}.

The real secret of the patented technology lies within the internal semiconductor structure of the diodes. They use 0.3µm CMOS technology and offer Schottky barriers as well as standard p-n barriers. To achieve this, p doted cones oriented to the cathode are placed in front of the Schottky barriers around the anode. When polarity changes, the Schottky junctions will conduct first and offer a low forward voltage, whereas the p-n junctions switching on later when current flow sustains enable highest current densities. In reverse mode, current will be blocked quicker and better: Whereas normal Schottky diodes suffer from high leakage currents, trench technology used in Qspeed diodes will generate additional areas of low carrier density around the p cones that will spread up to the Schottky barrier thus clearing it of carriers. This will stabilise the semiconductor and reduce leakage currents significantly, which would be up

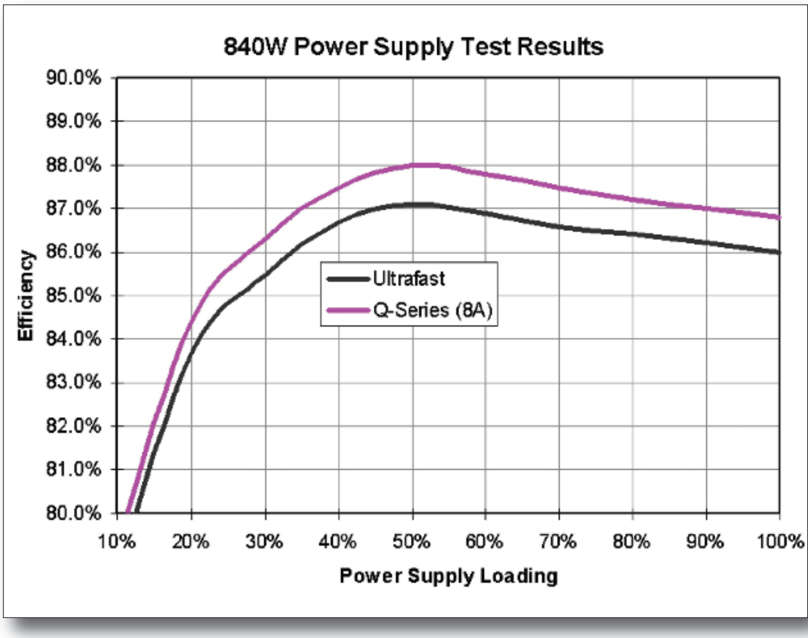

Figure 4: Increase in efficiency from normal ultra fast to Qspeed diodes in a PFC power supply using 100V input voltage and delivering 840W output power

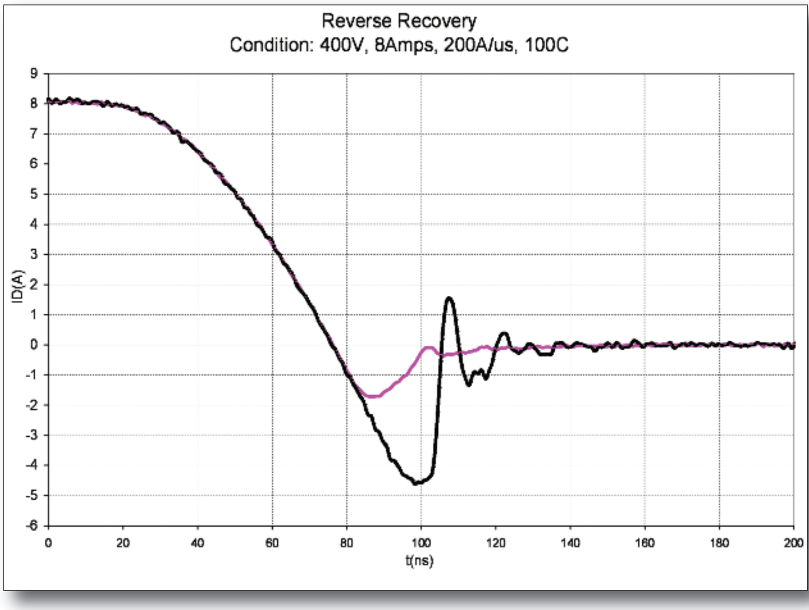

Figure 5: Comparison of reverse charge recovery times of Qspeed (magenta) and ultra-fast diodes (black)

to a few ten milliamperes with diodes of this size otherwise.

Schottky and p-n combined

Another advantage of Qspeed diodes is their size. SiC is efficient, but also expensive, so SiC chips are kept very compact. An overload - no matter how short - can easily destroy the diode. Qspeed diodes on the other hand, use bigger chips, which is affordable in standard silicon technology, thus offering the robustness of a classical 2N3055 power transistor. Therefore, there is plenty of headroom to design them for an average current, rather than peak current, surviving spikes and transients without problems. Still, they are fast enough that power supplies with these diodes can run at 65 up to 100kHz, thus reducing size and cost of inductors.

Of course, the capabilities of the new diodes are not limited to power factor correction. In standard rectifying circuits, their soft switching is also an advantage. When “ultra fast” diodes would produce such strong ringing that damping with RC elements becomes necessary to prevent the components from being destroyed by going over their maximum reverse voltage, Qspeed diodes do not suffer from ringing even without damping, which raises efficiency up to 2%. Also their temperature behaviour is much better (Figure 6). Up to 105°C Qspeed diodes outperform even SiC!

At first glance, Qspeed diodes may cost a bit more than simple ultra fast diodes. But those costs are offset by using a smaller MOSFET. Lower costs and higher reliability also result by eliminating EMI filter components. Additionally, more efficient circuits may be used: Instead of using DCM - discontinuous conduction mode - common in current designs, wanting to keep high losses low that result from diodes with high Q_{RR} by reversing charges less often, CCM - continuous conduction mode - may be used, which offers simpler regulation circuitry and lower switching currents. This way, completely new designs with high efficiency and compact size become possible.

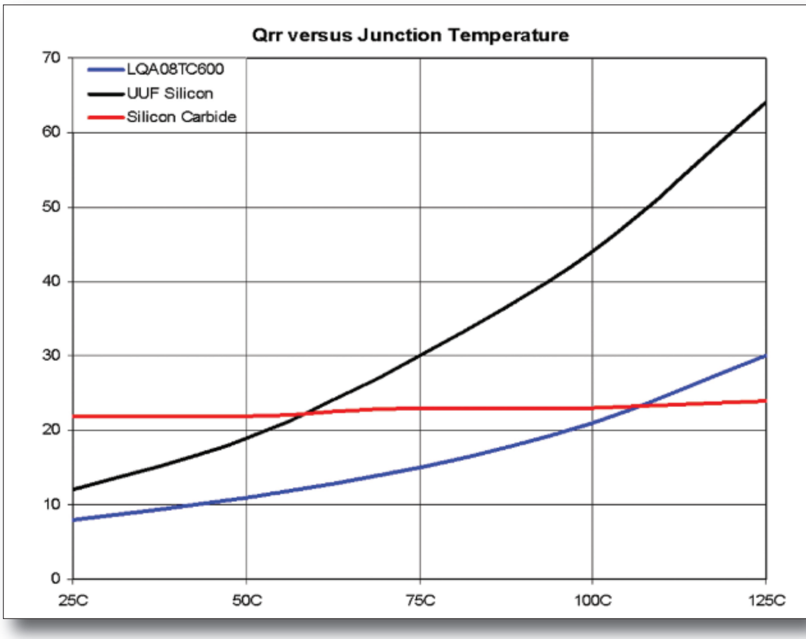

Figure 6: QRR with rising junction temperature at SiC (red), ultra fast (black) and Qspeed diodes (blue)