

Electrical Behaviour of a New Gallium Arsenide Power Schottky Diode

A. Lindemann
IXYS Semiconductor GmbH
Postfach 1180
68619 Lampertheim, Germany
Fax: ..49/6206/503-579
E-Mail: A.Lindemann@IXYS.de

St. Knigge
Ferdinand Braun Institute
Rudower Chaussee 5, Geb. 11.10
12489 Berlin, Germany
Fax: ..49/30/6392-2685
E-Mail: St.Knigge@ieee.org

Keywords

Power semiconductor devices, New devices, High power discrete devices, Emerging technologies, High frequency power converters

Abstract

This paper presents new gallium arsenide power Schottky diodes with blocking voltages of some hundreds of volts. Chips have been developed, processed and packaged. Electrical measurements show exceptionally fast reverse recovery and low forward voltage combined with high temperature capability and low parameter variations. These results promise the new diodes will permit further progress in high frequency power converter technology.

1 State of the Art

In general silicon bipolar diodes are used in converters. Their reverse recovery generates losses in the diode and in the corresponding transistor in hard switching circuits [1]; it may furtherly be a limiting factor in soft switching circuits as well [2]. Some effort is spent to optimize silicon bipolar diodes' behaviour [3] which however cannot exceed the physical limits.

Silicon schottky diodes [4] are an alternative: Their reverse recovery, characterized by specific resistance and junction capacity, is fast; however due to the specific resistance blocking voltage capability is considered to be limited around 100V. Additionally diodes with materials not commonly in use - new materials - are proposed such as silicon carbide [5].

This paper presents a new diode combining a Schottky contact with a new material - gallium arsenide.

2 Technology

2.1 General

This section gives a brief survey of the technology of the chips used and the components consisting of the new chips in a package. Thus it provides the necessary information for the understanding of the electrical behaviour of the gallium arsenide Schottky diodes being the subject of this paper.

2.2 Chips

Gallium arsenide (GaAs) base material is used. Mobility of electrons in GaAs is 5.6 times bigger than in silicon (Si) and energy band gap is larger which results in a significant reduction of on resistance compared to silicon, or, in other words, a lower forward voltage drop [6]. The advantage of Schottky contact only using majority carriers in combination with the high mobility leads to very fast switching behaviour. Furtherly due to the larger energy band gap the critical electrical field for breakdown is higher than in silicon, or, in other words again, blocking voltage capability of the GaAs Schottky diode is

higher than of a Si Schottky diode with a comparable forward voltage. Finally temperature dependence of electrical parameters is small.

In order to profit by these outstanding material properties of GaAs a four mask level GaAs power Schottky diode process was developed. It is based on commercially available n⁺-GaAs substrates and metalorganic vapour phase epitaxy (MOVPE) grown epitaxial layers of about 10µm thickness. In addition to this quite high thickness for MOVPE technique reproducible control of n-doping level of 10¹⁴ .. 10¹⁶ cm⁻³ depending on the desired blocking capability of the diodes had to be mastered. Using a multiwafer planetary reactor (up to 5 x 4" load per run) as well as a fully automated wafer track for resist coating and spray development, a lift off processor and projection lithography by an i-line wafer stepper (suitable for 2", 3" and 4" wafers) in processing, the chip fabrication is done on a 3" line at the present. These modern processing tools are giving the opportunity to scale up easily to a 4" line.

An important aim during the process development was that the GaAs Schottky diodes can be handled in soldering and bonding like present Si devices. Furthermore they had to be capable to be integrated together with silicon based devices into power electronic modules. Hence, a thick nickel layer covers the ohmic backside contact of the devices and the Schottky contact on the front side is coated with a 2µm aluminium layer.

2.3 Packaging

Different types of components contain diode chips of this family: Different chip sizes with the respective current capability, different blocking voltages and pinouts are available; all components are TO220 packaged - see Table I. It is intended to extend the current and voltage range in the course of time.

Table I: types of components containing the gallium arsenide diode chips

| type | pinout | rated voltage U _R | rated current I _F DC at T _C =95°C |
|--------------------|------------------------------|---------------------------------|--|
| DGS10-018A | single diode | 180V | 10A |
| DGS10-025A | single diode | 250V | 10A |
| DGSK20-018A | double diode, common cathode | 180V | 10A per diode |
| DGSK20-025A | double diode, common cathode | 250V | 10A per diode |
| DGS20-018A | single diode | 180V | 20A |
| DGS20-025A | single diode | 250V | 20A |
| DGSK40-018A | double diode, common cathode | 180V | 20A per diode |
| DGSK40-025A | double diode, common cathode | 250V | 20A per diode |

3 Electrical Measurements

3.1 General

This section shows results of electrical measurements obtained with the components as briefly described in section 2: Static and dynamic measurements taken with DGSK40-018A - see Table I - are documented. They can be considered to be representative for the new family of gallium arsenide Schottky diodes being based on the same technology. To gain information being relevant for applications most measurements have been taken under typical operating conditions; in addition, some investigations have been carried out under extreme conditions, which exceed the ratings of the gallium arsenide components by far, to show further capabilities and limits normally not accessible.

Additionally the characteristic data of the gallium arsenide diodes are complemented with values of

silicon diodes with a comparable chip size and blocking voltage also produced by IXYS; they have been evaluated in the same experimental setup. These indications are intended to permit to compare the behaviour of the well known and the new technologies.

3.2 Static Characteristics

Static characteristics refer to the states of conduction and blocking.

For the state of conduction forward voltage at room and elevated temperature are plotted in Figure 1. Taking into account the fact that this device will preferably be used in high frequency applications due to its superior dynamic behaviour - see section 3.3 - two conclusions can be drawn: First, forward voltage in the interesting range of operating currents is low; second, due to the fact that temperature coefficient of forward voltage turns positive for currents above some less than 10A, a parallel connection of these devices will automatically symmetrize.

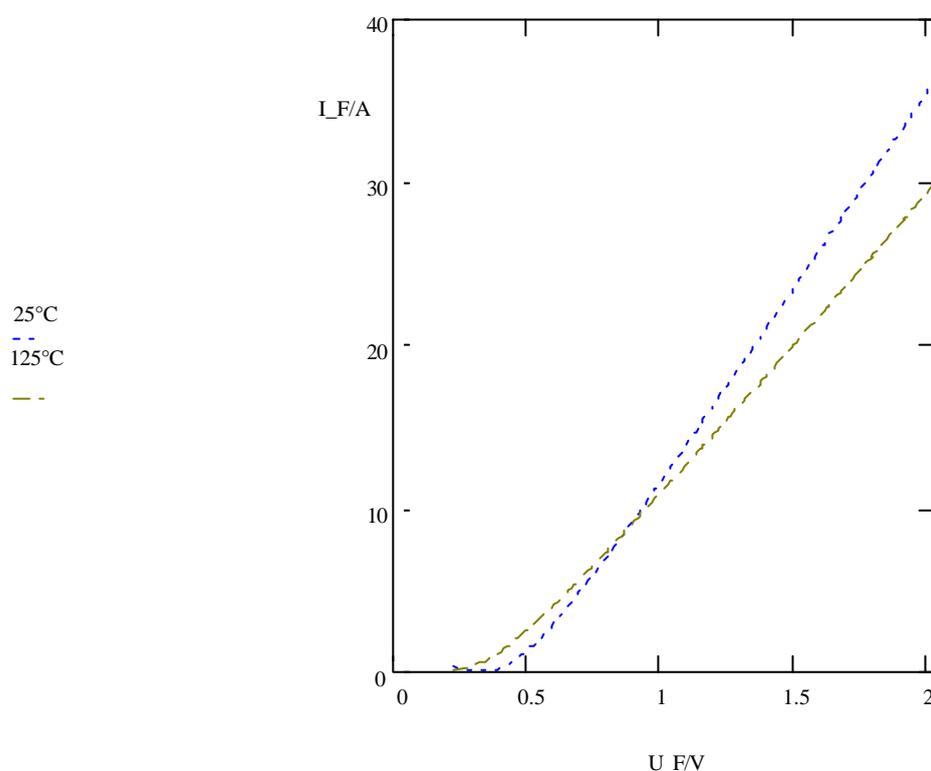


Figure 1: typ. forward current versus voltage drop; horizontal: U_F/V ; vertical: I_F/A , at 25°C (dots), 125°C (lines)

In addition to the curves in Figure 1, Table II gives a value of forward voltage; as mentioned, for comparison forward voltages of a type of Schottky and bipolar silicon diode are indicated: The advantage of the Schottky diodes having a significantly lower forward voltage than the bipolar diode can be clearly seen. Comparing the values for the Si and the GaAs Schottky diodes the lower blocking voltage of the Si type, which is favorable for a low forward voltage, should be taken into account; in the following, further distinguishing features will be mentioned.

Table II: typical forward voltage

| type | U_F/V at $I_F=8A$, $T_J=25^\circ C$ |
|-------------------------|--|
| DGSK40-018A | 0.82 |
| Si Schottky 130V | 0.68 |

bipolar Si 200V | 1.1

With respect to blocking behaviour, also belonging to static characteristics as mentioned above, typical diode characteristics can be stated: Leakage current is specified to be maximum 2mA up to the breakdown voltage, while it increases significantly above breakdown voltage - see also Table I. As an experiment a component has been heated up up to $T_J=275^\circ\text{C}$ which exceeds the specified temperature range of $T_J<150^\circ\text{C}$ by far; such chip temperatures of course should not occur during operation, which is partially caused by constraints of standard packaging, however results on blocking characteristics of the chip at high temperatures could be obtained: Particularly in the upper temperature range an exponential increase of reverse current through the diode becomes evident as can be expected by semiconductor physics.

3.3 Dynamic Characteristics

The dynamic measurements have been taken with a low inductive experimental setup with special regard to an accurate current probing. Its schematic - a hard commutated chopper circuit - is shown in Figure 2.

The turn off waveforms of forward current I_F and reverse voltage U_{KA} are plotted in Figure 3 for cold and in Figure 4 for hot switching respectively. The data that can be gained out of the waveforms are listed in Table III; please note the gallium arsenide Schottky diode's high switching speed and low reverse recovery current peak, caused by junction capacity. Again, such as in Table II, the indicated data are complemented by values measured in the same experimental setup for comparable chips of other technologies. Comparing them, several conclusions can be drawn: The GaAs diode shows the smallest reverse recovery current peak with a rather soft turn off. As could be expected the Schottky diodes have a shorter reverse recovery current peak with less amplitude compared to the bipolar version. Contrary to both types of Si diodes the GaAs diode additionally shows a switching characteristic which is independent from temperature. To check possible limits of this temperature invariance the high temperature investigation as described in section 3.2 has been extended to switching behaviour: Rising chip temperature up to $T_J=275^\circ\text{C}$ mainly results in a higher static leakage current after the reverse recovery of the diode, however the switching waveforms themselves only show a slight prolongation of reverse recovery at the highest temperatures; thus switching is hardly influenced by temperature.

It can be concluded the dynamic behaviour of the gallium arsenide Schottky diodes also meets the physical expectations as expressed in section 2.2.

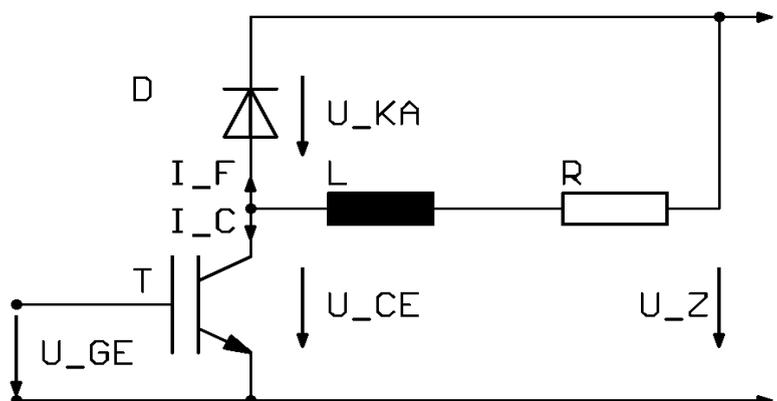


Figure 2: schematic of the experimental setup

Table III: typical dynamic behaviour

| type | t_{rr}/ns | I_{RM}/A | t_{rr}/ns | I_{RM}/A |
|------|--------------------|-------------------|--------------------|-------------------|
|------|--------------------|-------------------|--------------------|-------------------|

| | at $T_J=25^\circ\text{C}$ | | at $T_J=125^\circ\text{C}$ | |
|-------------------------|--|-----|----------------------------|-----|
| | at $I_F=2\text{A}$, $di_F/dt=200\text{A}/\mu\text{s}$, $U_Z=100\text{V}$ | | | |
| DGSK40-018A | 14 | 1.8 | 14 | 1.8 |
| Si Schottky 130V | 20 | 2.2 | 14 | 1.9 |
| bipolar Si 200V | 15 | 2.2 | 26 | 3.2 |

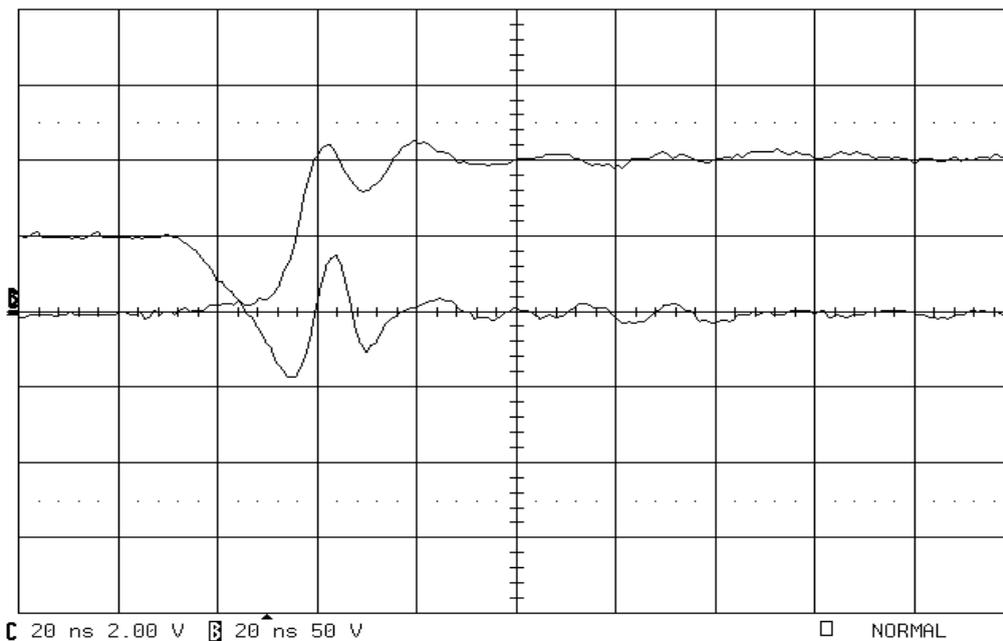


Figure 3: turn off waveform of DGSK40-018A at $T_J=25^\circ\text{C}$: horizontal: time t , 20ns/div; vertical: diode current I_F , 2A/div and diode voltage U_{KA} , 50V/div

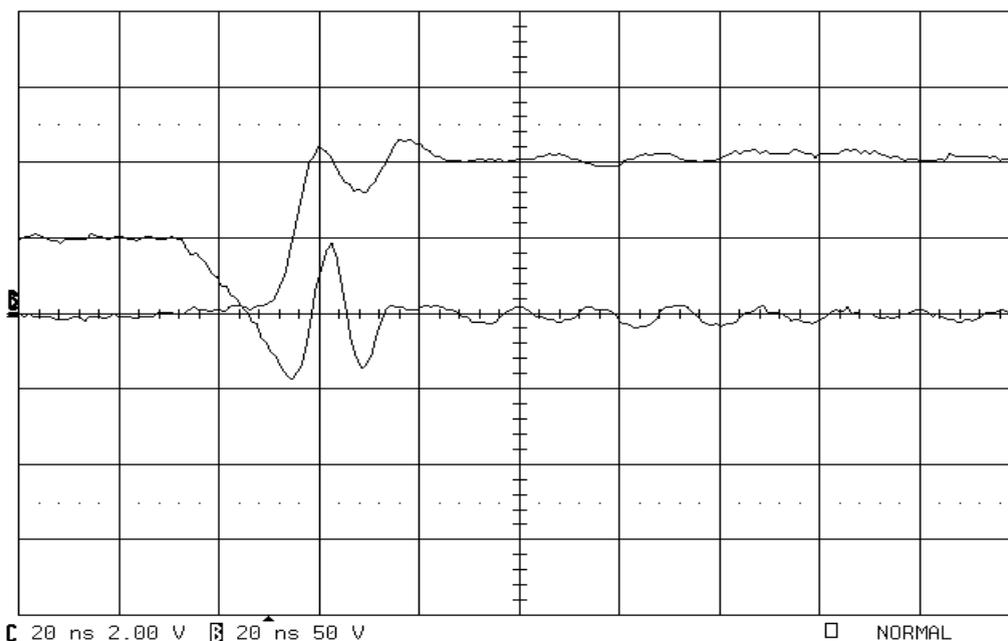


Figure 4: turn off waveform of DGSK40-018A at $T_J=125^\circ\text{C}$: horizontal: time t , 20ns/div; vertical: diode current I_F , 2A/div and diode voltage U_{KA} , 50V/div

The trade off between fast reverse recovery and low forward voltage is well known from bipolar silicon diodes - the best design is represented by the lowest characteristic curve in the $I_{RM}(U_F)$ diagram. Differences in chip design situating gallium arsenide Schottky diodes in different points of their $I_{RM}(U_F)$ diagram have been observed in the course of design, process elaboration and comparison: A variation on gallium arsenide chips with a different design shows almost the same dynamic behaviour as listed in Table III, but forward voltage is 25...30% higher than the value for the DGSK40-018A - see Table II. This underlines the necessity to carefully optimize chip design.

4 Conclusion

A new gallium arsenide Schottky diode has been presented. Compared with state of the art bipolar silicon diodes its operational behaviour is outstanding, both with respect to conduction and switching.

This type of diode is expected to give an important contribution to new converter designs: Fast commutation permits the use in converters with an increased switching frequency. Miniaturization efforts for this kind of high end converters are supported by the diode's low conduction losses and high temperature stability permitting the use of a small chip or package respectively, reducing space, weight and expense for cooling.

References

1. Kolar, J., Ertl, H., Zach, F: IXYS-VUM25-E - A New Isolated Power Module for Low-cost/Weight/Volume High Performance Three-Phase Sinusoidal Input Current Power Conditioning; Power Quality, Bremen, 1995
2. Bernet, S.: Characterization and Comparison of IGBTs and MCTs in Zero Current Switching Converters; EPE, Trondheim, 1997
3. Lutz, J.: Axial Recombination Centre Technology for Free Wheeling Diodes; EPE, Trondheim, 1997
4. Power Schottky Rectifier Diodes, HiPer Fast Recovery Epitaxial Diodes; IXYS, Lampertheim, 1998
5. Bruckmann, M., Baudelot, E., Weis, B., Mitlehner, H.: Switching Behaviour of Diodes Based on New Semiconductor Materials and Silicon - a Comparative Study; EPE, Trondheim, 1997
6. Baliga, B.J.: Power Semiconductor Devices; PWS Publishing Company, Boston, 1995