ABSTRACT

An overview is given about solid state pulse power switches which are designed for single pulse applications i.e. launch systems (ET or EM Guns) and active armour. Also a newly developed switching system is presented which can be used for repetition frequencies up to 400 Hz, high di/dt, up to 20 kVdc and pulse currents of over 15 kA, designed for laser applications. (Solid State alternative for Thyatrons) By using a modular platform technology, a variation of four standardized silicon wafer sizes can be selected to reach the required current and di/dt levels, and by stacking devices in series connection, voltages of up to 50 kV can be realized. The presented switches and components are including the triggering system, and where required, also including power supply and heatsinks.

INTRODUCTION

Since several years ABB is supplying solid state switches and components which are based on a wide range of specific devices which are designed for non-repetitive pulsed power applications. More recently interest has been shown in fast Semiconductor Switches which can be used at medium frequencies, as alternative solution for thyatrons or ignitrons, because of longer life, less maintenance, no use of mercury, and uncritical positioning. Especially for the last ones, ABB has designed a new platform technology and is using this concept in a range of different rated switches. These switches are so called Power Parts, as they are built-up as a complete assembly with the semiconductor itself, driver, clamping, ev. cooling, power supply and optical triggering.

SEMICONDUCTOR DEVICES

The special devices for Pulsed Power supplied by ABB are ranging from High Voltage Multichip Thyristors and Multichip Diodes for single shot applications to highly interdigitated devices with integrated driver units for high current and very high di/dt applications with pulse repetition rates of up to 400 Hz. Wafer sizes with overall diameters of 51, 68 and 91 mm are most common for pulsed power applications, and form the base for our product range, however large sizes up to 120 mm are possible. One of the oldest devices used for single pulse switching is the famous Multichip Thyristor which is one component with 4 wafers in series connection. This device was developed together with I.S.L. Saint Louis, France [1], industrialized by ABB Semiconductors AG and produced since 1996 in quantities of several hundred pieces for the I.S.L. Pegasus 10 MJ Railgun System. A corresponding diode was developed and produced at
the same time, using the same ceramic housing and mechanical size, but using 6 wafers in series connection. This component is also often in designed as crowbar diode in other applications because one of the advantages is the very compact size. Housing diameter is 75 mm and total height is only 50 mm. The blocking voltage of these Multichip devices is V_{rrm} 12 kV and versions with V_{rrm} 13.5 kV are available. A special trigger unit for simultaneous triggering of all 4 wafers is available as separate item. This trigger unit includes also the voltage sharing resistors for each thyristor wafer. Because of the mechanical structure of these devices, which does not allow active cooling of all the wafers, the devices can only be used for single pulse applications. The di/dt capability of these switches is also limited, and in the range of 600 – 800 A/µs.

World wide several projects and systems are equipped with the Multichip components and also series connection of devices is very common. Fig. 3 is showing a coaxial built-up of 3 devices 5SDA 27Z1202 in series connection for blocking voltage of 36 kV, and capacitor charge voltage of 24 kVdc. As protection large disc resistors of total 0.1 Ω are used in series connection with the diodes.

As the mentioned Multichip devices where designed for a specific project only, other requirements are often demanding higher currents, higher di/dt’s and different specifications. For this type of applications ABB has since 1995 two devices available with very strong interdigitated gate structures and wafer sizes of ∅ 68 and ∅ 85 mm. These components are specially designed as very fast on-switches, without switch-off capability, and mostly in use as
capacitor discharge switches, where very high di/dt’s of up to 20 kA/µs are often required. These devices are using only one asymmetric blocking wafer per housing, the forward blocking voltage is Vdrm 4.5 kV and reverse blocking is only Vrrm 18 V. Because the devices can be active cooled if assembled between heatsinks, there is a possibility to use them at repetition frequencies of up to several hundred Hz, depending on the pulse length and pulse height. The mentioned devices come in standard glazed ceramic semiconductor housings and can be stacked in series connection to reach higher blocking voltages. ABB can supply complete tested assemblies with semiconductor devices, heatsinks and isolated clamping material.

To reach higher performance, to reduce induction between switch and driver board, and to avoid that equipment makers have to worry about driving units, ABB has designed devices with integrated driver units. This was done in combination with a very low induction semiconductor housing, with several through connections. (See Fig. 6) This combination of low induction housing, integrated driver board, and special treatment of the GTO-like silicon wafer with a buffer layer to reduce silicon thickness, has increased the di/dt and switch-on behavior of the devices tremendous. To reduce induction between the switching component and the freewheeling diode, the last one can be included in the switching wafer of the so-called Reverse Conducting version. The ratio between switch part and diode part is about 2/3 for the switch and 1/3 for the diode. Fig. 7 shows a capacitor discharge switch with integrated driver unit for a 91 mm silicon wafer.

The large 91 mm device with asymmetric or reverse blocking wafer is capable to block 4.5 kV and has a cosmic ray withstandability of 3 kVdc. Pulse Currents of up to 150 kA @ tp = 50 µs and di/dt of up to 30 kA/µs are possible. The energy for the driver unit is taken direct from the anode side of the device, from the main capacitor (bank) and gives the advantage that no
separate power source is needed. By using this technology it is not required to have external power supplies, and makes the isolation between the driver units easier to handle. To reach higher voltages it is easy to use these devices in series connection because the sharing resistors are already integrated on the driver unit. Fig. 8 shows an example of a switch assembly with 91 mm wafers, a max. Charge voltage of $V_{dc} = 10$ kV, $I_{pulse} = 100$ kA @ $t_p = 50$ µs exponential decay, $\text{di/dt}$ of about $10$ kA/µs and repetition rate of 1 shot per 20 sec. With this rep. rate it is not required to use active cooling of the devices. The overall size of a 10 kV / 100 kA switch can be as small as 300 x 325 x 230 mm. This type of devices are also used for electromagnetic protective systems (active armour) were an orthogonal coil system is energized with a high $\text{di/dt}$, high current pulse to launch a metal plate to protect the combat vehicle for damage from foreign projectiles or missiles.[2]

Fig. 8) Non Repetitive 10 kV / 100 kA Discharge Switch with parasitic Driver Unit supply from main voltage source. Devices: 4 x 5SPY 36L4502 (91 mm wafer)

Fig. 9) Repetitive, reverse conducting, water-cooled 10 kV / 13 kA / 300 Hz Discharge Switch with Driver Unit energy supplied a by separate closed loop current source Power Supply. Devices: 4 x 5SPR 26L4506 (91 mm wafer)

Fig. 9 shows a switch assembly for repetitive applications. This switch has the same built-up as the non-repetitive one in fig. 8, but now a separate closed loop current source power supply is used to energize the driver units. Water cooled heatsinks are used to enable higher switching frequencies in the range of up to 400 Hz, in combination with peak currents of $I_p = 13$ kA @ $t_p = 12$ µs. This type of switches can be made with reverse conducting components, where the freewheeling diode is monolithic integrated on the same silicon wafer. The reverse conducting repetitive switch assemblies are getting more and more popular as solid state alternatives for thyatron or ignitron applications [3], for example to drive high power lasers, high power micro wave systems, or radar systems. The described switches can be mounted in any position and can be optimized for a wide range of applications. The technology used in these concepts is mainly for pulse widths of minimum 1 µs or longer. ABB is offering here a platform technology with 3 different silicon sizes, i.e. 51, 68 and 91 mm O.D. for different pulse currents and life-time conditions. Switch assemblies with blocking voltages up to 50 kV are possible.
NEW DEVELOPMENTS

The components and switches presented before, are state of the art in the year 2001, and will be used for applications where with pulse durations longer as 1 µs. As several applications, like Lasers, Modulators etc., are working with short pulses, and switch-on / switch-off technology, the IGBT devices are becoming interesting. Since IGBT’s are produced for blocking voltages of 2.5 and 3.3 kV it is possible to reach the 10 kVdc range with only 6 to 8 devices in series connection. Conventional IGBT Modules, which are designed for drive applications are using bonding technology and have undefined paths from the screw terminals to the individual chips. This way of series connection has relatively high induction and is not optimized for pulsed applications. In failure mode the bonding wires will burnout and cause an open circuit condition, which results in a total failure of the switch. In worse case even explosion of the Module housing was observed. For these reasons the pressure contact IGBT was developed where every IGBT chip has its own contact pad and no wire bonding. ABB has since several years experience with high voltage pressure contact IGBT’s for HVDC (High Voltage DC transmission) systems and is starting to use these HV press pack devices for Pulsed Power Applications if higher frequencies on/off switching is required. It is expected to reach up to 2 kHz at medium di/dt values. This development can be interesting for medical- and radar systems, and is expected to be available for this market by mid 2002. IGBT and Diode chips can be combined in small sub-assemblies, which are placed in a holder. Fig. 10 is showing a press-pack module with six IGBT sub-assemblies. (Rated 2500V/2500A) Each sub-assembly can contain 9 or 15 pcs IGBT or Diode chips, or a combination of both.

Fig. 10
Press-Pack IGBT Module with 6 Sub-Assemblies
and one 9 chip sub-assembly (2.500V)

Versions with higher blocking voltages are developed and will become available from the second half of 2002, after extensive tests are finished.

RELIABILITY

For higher pulse repetition rates it is important to calculate the total expected life-time of the semiconductor device. Semiconductors are aging by temperature increase per pulse. The Δt per pulse is an indication and extra polated by quantity of pulses gives very fair indications about the expected life-time. Computer programs enable to calculate the temperature increase per pulse and related to the size of the silicon a life-time estimation can be predicted. Field experience has shown that for the 91 mm reverse conducting devices, values of over 100 Mio shots with 60 kA and di/dt ≤ 30 kA/µs are possible without device failures. Most important here is a proper clamping, low inductance connections and the cooling of the device. Since summer 2000 several switch assemblies for 10 and 20 kVdc with different device sizes are in successful
These switches are in use with repetition rates of 10 – 400 Hz. For the IGBT versions there are no reliability figures available for pulsed power applications as these products from ABB are not introduced in this market till today.

CONCLUSION

It has been shown that ABB Semiconductors AG produces a range of specific designed components assembled as complete switches which are fulfilling a wide demand for single pulse or repetitive use in pulsed power applications in military and civil areas. Circuit requirements and reliability considerations make it favorable to realize a very close interaction between the power semiconductor device, the driver unit, the power supply, the mounting stack and testing. The technology platform and switches which ABB has designed is an interesting alternative to other switching technologies from reliability, life-time, maintenance and environmental point of view.

REFERENCES

