

# Fast High Voltage Solid State Switch Using Insulated Gate Bipolar Transistor for Discharge-Pumped Lasers

Nur Syarafina Binti Othman, Tsubasa Jindo, Makato Yamada, Miho Tsuyama, Hitoshi Nakano

**Abstract**—A novel method to produce a fast high voltage solid states switch using Insulated Gate Bipolar Transistors (IGBTs) is presented for discharge-pumped gas lasers. The IGBTs are connected in series to achieve a high voltage rating. An avalanche transistor is used as the gate driver. The fast pulse generated by the avalanche transistor quickly charges the large input capacitance of the IGBT, resulting in a switch out of a fast high-voltage pulse. The switching characteristic of fast-high voltage solid state switch has been estimated in the multi-stage series-connected IGBT with the applied voltage of several tens of kV. Electrical circuit diagram and the mythology of fast-high voltage solid state switch as well as experimental results obtained are presented.

**Keywords**—High voltage, IGBT, Solid states switch.

## I. INTRODUCTION

**P**ULSED power is a broad technical field that is united by a common activity which is the transformation of electrical energy into high peak power pulses. The pulsed power achieves in many variety of applications. For some instances, in the industry, pulsed power drives the lasers that do the raw work of cutting and welding as well as the lasers that do the delicate work of semiconductor fabrication with intense ultraviolet radiation [1].

Most of gas lasers are provided the electrical energy by fast-high voltage switch such as a spark gap, a thyatron, a krypton and others. However, each fast-high voltage switch is based on the discharge phenomena, the switching characteristics are unstable. Thus, the solid state switch is required to realize the stable operation in laser system.

The recent advancements in new solid state devices and high energy density components have enabled pulsed power system to remain powerful yet shrink in size and weight [2]. The solid state switch in pulsed power supplies is typically used for the excitation of CO<sub>2</sub>, TEA, and excimer laser with extremely high peak power pulses. Although many pulsed power supplies for CO<sub>2</sub>, TEA, and excimer laser still make use of thyatrons, there has been a strong drive to replace the older thyatrons with modern solid states switches. Solid state switches have significant advantages compared to thyatrons which include longer service lifetime, low cost, and better availability.

A variety research effort for military and industrial interests

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have produced many component advancements for pulsed power engineers who are interested in smaller solid state switching systems. One of the most significant advancements in switching is the invention of the IGBT by B. J. Baliga in 1982 [3]. Due to that, a fast high-voltage solid state switch has been developed by using IGBTs.

A simple and flexible new method of the fast-high voltage solid switch with working-voltages of several kilovolts by the multiplication stage of IGBT in a series connection and an avalanche transistor circuit act as a gate driver is proposed to realize a stable, solid-state switch for discharge-pumped lasers.

## II. RESEARCH MYTHOLOGY

### A. The Configuration of Gate Driver Circuit

An avalanche transistor circuit is used as the gate driver to charge the larger input capacitance of the IGBT in order to operate IGBT in fast switching time.

Fig. 1 shows an avalanche transistor works. It is connected to a gate of IGBT which is referred by the method reported by Baker et al. in 1990 [4].

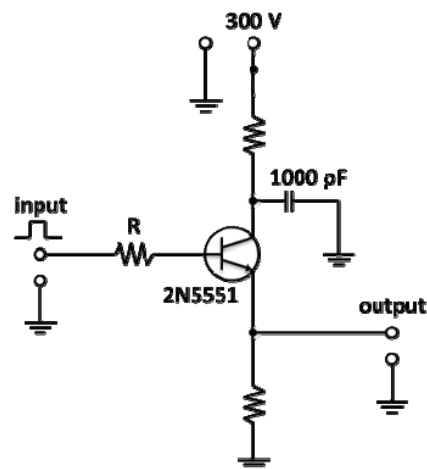


Fig. 1 Avalanche transistor circuit

In order to operate IGBT in fast switching time, fast pulse with low impedance should be introduced to the gate circuit of IGBT. A fast nanosecond pulse is generated by the input trigger. Fast output pulse from avalanche transistor circuit is applied to the bottom gate of the IGBT. By increasing the current drive capability to charge the input capacitance of the IGBT rapidly, the IGBT has turned on quickly.

Avalanche switching relies on avalanche multiplication of current flowing through the collector-base junction as a result

of impact ionization of the atoms in the semiconductor crystal lattice. Avalanche breakdown in semiconductors has found application in switching circuits.

Avalanche transistor (2N5551) has been used since the switching speed is easily obtained less than 5 ns at an applied voltage of 300 V.

#### B. The Compact of Multi-stage IGBT in a Series Connection

Power semiconductor device technology has been continually developed far to get higher voltage and current ratings, lower conduction and switching losses and easier to drive. As a result, MOS-Bipolar Transistors such as the IGBT present interesting characteristics combining both MOS and bipolar structures with very desirable features for power systems designers-mainly the high input impedance allowing comparatively small gate drivers, the short circuit withstand capability and robust turn-off performance.

IGBT integrates a MOSFET with a bipolar transistor to switch large amounts of power with very tiny control voltage [5]. By taking advantages of the power handling capability and extremely high switching speed of the bipolar and combining it with MOSFET's low gate power, the resulting IGBT is a very high power hybrid with enormous power gain.

IGBT and other field affect switching devices have dramatically grown in power handling capacity, diminished in cost, revolutionized power conversion method worldwide [6]. The modern IGBT switches kilo-amperes of current at the multi-kilovolt level and achieves it all with very low losses.

IGBT is a device capable of high speed and large current operation. However, if used only one IGBT, the switching of high voltage required for the discharge-pumped laser is very difficult. Therefore, for high voltage applications, the series operation of devices is necessary to handle high voltage with limited voltage rating devices. The switch operating voltage can be increased and associated switched peak current is reduced by connecting IGBTs in series.

In order to drive approximately 10 kV of output voltage for discharge-pumped laser, 8 stages of IGBT is connected in series. IGBT (GT40T321) has been used and its withstand voltage is 1500 V.

Connecting IGBT in series allows fast high power high voltage semiconductor switches with working voltages of several kilovolts is to be realized [7].

### III. EXPERIMENTAL

The switching characteristic of fast-high-voltage solid state switch has been estimated in the eight series-connected IGBT. Fig. 2 shows a circuit of 8 stages of IGBTs in a series connection.

The operation method is described as follows, by applying a voltage of 300 V, avalanche break down is occurred. It generates a fast nanosecond pulse with the input trigger signal.

The high voltage is applied from DC power supply to the IGBTs. At the same time, the capacitors (C2~C8) are charged. The voltage of each IGBT is divided by the resistances which are connected between collector and emitter of the IGBT.

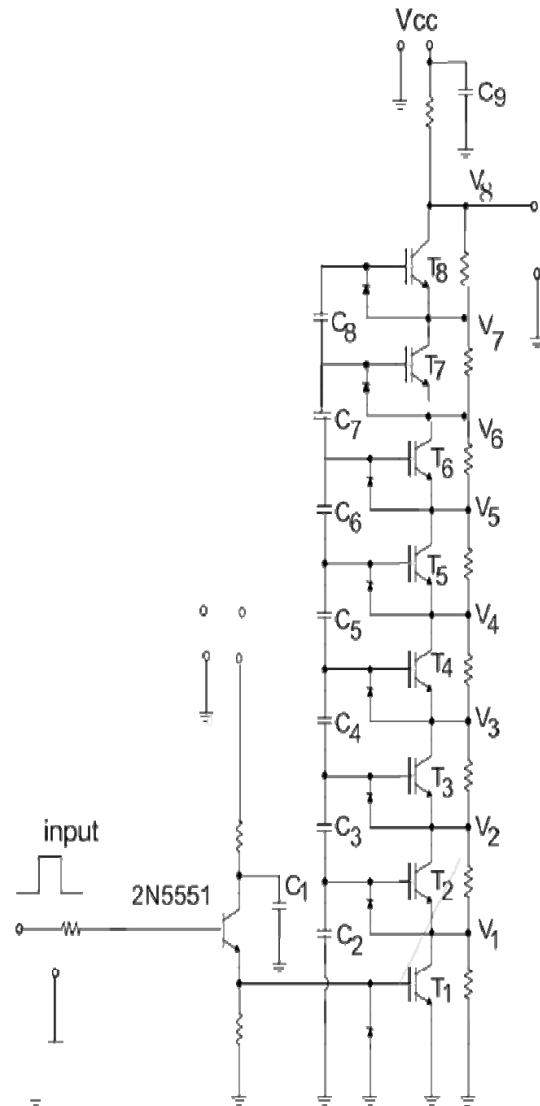


Fig. 2 A fast high voltage switch produced by 8 stages of IGBT in a series connection

Fast output pulse from the avalanche transistor circuit is applied to the bottom gate of IGBT (T1). When the bottom gate of IGBT (T1) turns on, a voltage difference,  $V_1$  is generated between the ground and the emitter of T2.  $V_1$  is divided by C2 and the input capacitance of T2.

When the terminal voltage of C2 is sufficiently high enough to drive the gate, T2 turns on. Repeating this process turns T3 to T6 successively.

This circuit is compact and inexpensive since a drive circuit for each gate does not required.

The voltage difference between the emitter and ground of each IGBT increases from bottom to top stage of IGBT. The appropriate value of capacitor (C2~C8) is necessary to stable switch out and to prevent the IGBTs from damage. The value of capacitors (C2~C8) proposed are 800 pF, 690 pF, 470 pF, 330 pF, 220 pF, 100 pF and 100 pF respectively.

From bottom to top stage of IGBT, the value of capacitor is reduced to constant the voltage at each gate of IGBT. In addition, a zener diode is connected between the gate and the emitter of each IGBT for gate protection from an excessive voltage.

#### IV. RESULTS

The switching characteristic of each stage of IGBT is measured with high voltage probe, having high frequency response. Fig. 3 shows the switching waveform at 8800 V in applied voltage. Table I summarizes the relation between switching time and applied voltage for the stage 1 to 8 in series connection. In 10-90% from the maximum value of the output waveform switching time is evaluated.

From Table I, each stages of IGBT have been switched out when the high voltage is applied. Fig. 4 shows that the switching time for stage 8 of IGBT is estimated to be 17 ns at applied voltage of 8800 V. The switching time would depend on the capacitor that connected to each stage of IGBT.

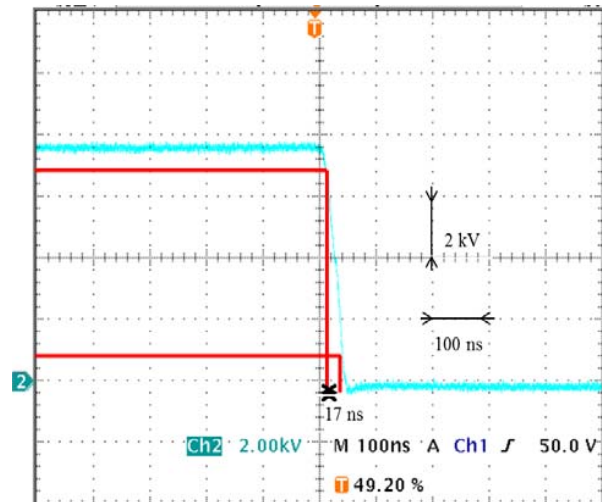


Fig. 3 Switching waveform stage 8 of IGBT at 8800 V

TABLE I  
SWITCHING TIME OF EACH STAGE FOR EACH APPLIED VOLTAGE

Applied Voltage (V)	Switching time of multistage IGBT (ns)							
	Stage 1	Stage 2	Stage 3	Stage 4	Stage 5	Stage 6	Stage 7	Stage 8
2000 V	28 ns	28 ns	28 ns	28ns	28 ns	27 ns	27 ns	27 ns
3000 V	27 ns	27 ns	27 ns	27 ns	26 ns	26 ns	26 ns	26 ns
4000 V	26 ns	26 ns	26 ns	26 ns	25 ns	25 ns	25 ns	25 ns
5000 V	25 ns	25 ns	25 ns	25 ns	24 ns	24 ns	23 ns	23 ns
6000 V	23 ns	23 ns	23 ns	23 ns	22 ns	22 ns	22 ns	22ns
7000 V	22 ns	21 ns	21 ns	21 ns	20 ns	20 ns	20 ns	20 ns
8000 V	20 ns	20 ns	19 ns	19 ns	19 ns	19 ns	18 ns	18 ns
8800 V	18 ns	17 ns	17 ns	17 ns	17 ns	17ns	17 ns	17 ns

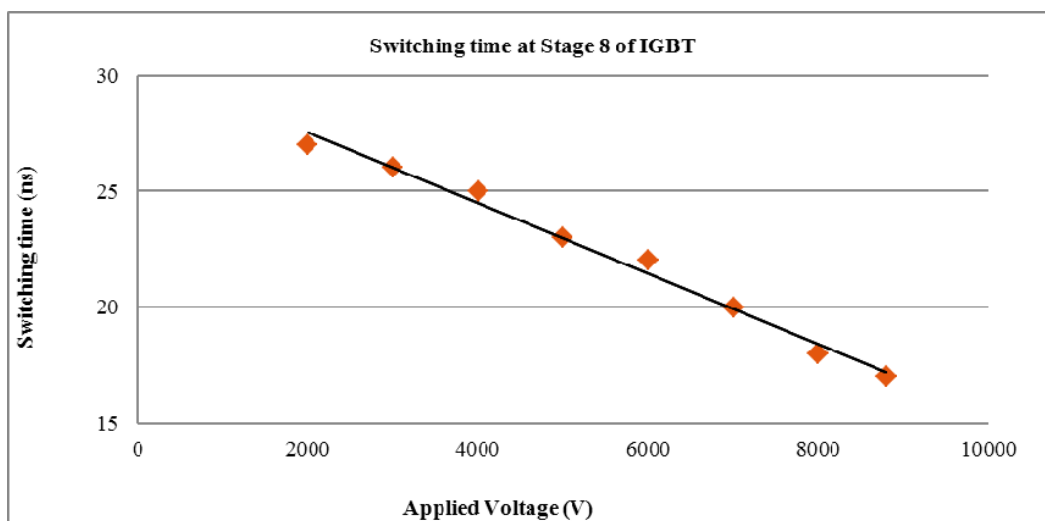


Fig. 4 The relation between the applied voltage and switching time

#### V. CONCLUSIONS

In this study, a fast high voltage solid switch with the multistage of IGBT in a series connection has been developed. The switching time of 17 ns has been achieved in the applied

voltage of 8.8 kV. The inductance of the overall circuit and the inductive high current noise will be considered in the future. The fast high voltage solid switch can be used for the excitation of CO<sub>2</sub>, TEA, and excimer laser in the future.

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