Characterization and analysis of Transistor Outline TO-254 Package for Power device applications

Shishir G. Patil,
Summer Intern,
CeNSE, IISc,
Bangalore, India

Pavithra B.,
Project Assistant,
CeNSE, IISc,
Bangalore, India

M.M. Nayak
Visiting Professor
CeNSE, IISc,
Bangalore, India

Abstract—*The vast advancements in Semiconductor Power Devices has led to increased deliberations in packaging of these devices. Primary among them are single IC stand alone systems. This paper considers TO-254 packaging for power devices. We observe the behavior of the specimen under different conditions mimicking the different environment exposed in the lifecycle of the device. Insulation Resistance, Breakdown Strength and other electronic properties are deliberated on.*

Keywords—Semiconductor Power Devices, Packaging, Transistor Outline (TO),TO-254, Insulation Resistance, Breakdown Strength, Hermetical Seal: Helium Leak Test, Temperature and Vacuum Effects, SEM: Scanning electron microscope analysis.

I. Introduction

A power semiconductor device is a device used as a switch and/or rectifier in electronic circuits. The use of IGBT's revolutionized their use in IC implementations. The adaptation of SiC and more recently GaN has brought in increased switching speeds and lower power consumption, thereby propelling their demand [1]. By some estimates more than 60 percent of all the power utilized in the United States flows through at least one power device and more often through multiple devices [1]. It is estimated that the worldwide market for Semiconductor power devices would reach $17 billion in 2020 [2]. Verticals including but not limited to aerospace, automotive and healthcare are expected to be the drivers for the exponential growth of semiconductor power devices based ecosystems. Industrial electronics and Consumer electronics are expected to equally leverage the developments.

Currently we can find semiconductor power devices being used in measurements of Blood Pressure meters, Accelerometers, Displays and recently Valves.

2010-2020 Power device market size

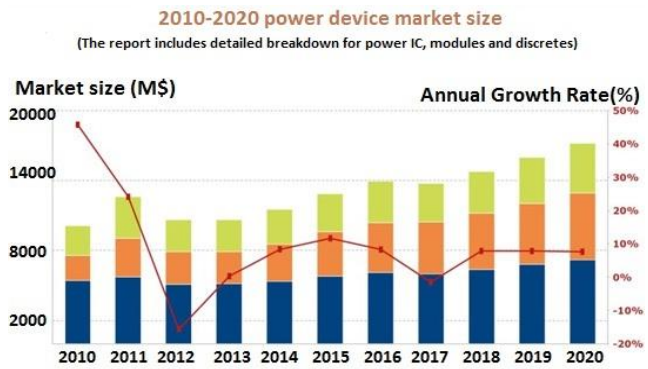

Fig. 1. *Expected increase in power devices [2]*

With new devices being invented and the expanding reach of the present devices for various applications, it calls for new considerations and challenges for packaging. While the optimization for consumer electronics would be function of cost and agility, for healthcare reliability, for others like aerospace and defense it is robustness.

The role of Packaging is to 1. Provide Mechanical Support 2. Connect to other dyes/subsystems electrically 3. Thermal Insulation or/and Heat Sink 4. Magnetic and Hermetical Sealing 5. Easy Handling 6. Vibration Damping and 7. Shock Protection

Defense and aerospace applications call for reliability and robustness for mission critical applications for which packaging of devices plays a critical role. In this paper we deliberate on the Transistor Outline(TO) packaging for power devices. The ease of attachment, with compatibility for various epoxies like (H20E, H77E, Epotherm 180 etc) for dye bonding and dye attachment and ease of wire-bonding make them preferred choice for packaging. In this paper TO packaging (TO-254) is characterized and behavior is reasoned out.

II. TO Packaging

TO packaging though initially started out for Packaging Ceramic dyes, it is being used increasingly for packaging of Electronic power devices as well amongst others.

A. General Properties

High Thermal Conductivity
High heat Resistance
High Insulation Resistance
High Breakdown Strength and
High Current Carrying Capacity
where current carrying capacity is defined by maximum lead temperature: 80°C (353K)

It is proposed to quantify and characterize the various properties experimentally, which are generally contemplated on; while arriving at a decision for choosing the right Packaging for the Semiconductor power device.

III. Structure And Schematic Representation of the Device Package

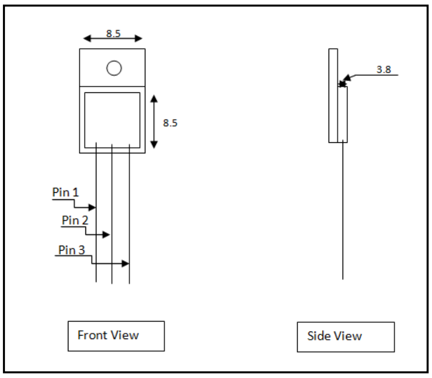

Fig. 2. *Device Schematics (All units in mm)*

The Lead material in TO-254 package is Alloy-52 (Cu Cored) with Nickel + Gold coating (Ni+Au). The heat sink is rated at 260W/mK [3]. This makes the device robust and augurs well with the coupling of a sink to its base(with suitable *thermally conductive* epoxy for dye-attach).

Characterization and Observations of TO -254 Package :

IV. Breakdown Strength Pin - Body

A. Breakdown Strength AC between Pin 1 to Body

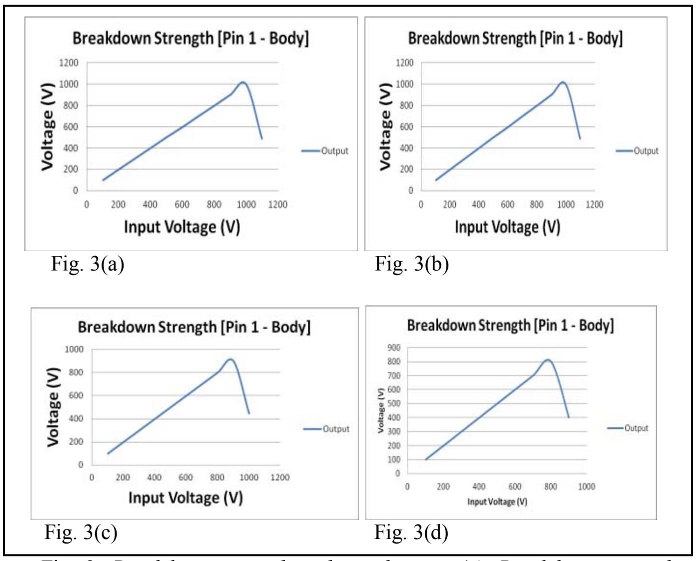

Fig. 3. *Breakdown strength without cleaning (a), Breakdown strength after cleaning with IPA(b), Breakdown strength after cleaning with Acetone(c), Breakdown strength after cleaning with Ultrasonic Bath Sonicator.*

A 60Hz AC signal with HI Set 01.00mA and Timer 001.0s GW INSTEK GPY-9804 Insulation Resistance/ Ground Bond Tester was used for observing the Breakdown strength between Pin1 to Body. Resolution 1μA for measuring current and 2V for setting voltage. The experiment was repeated for 4 cycles, initially in out-of-box condition, then after cleaning and Infrared (IR) Dry for 5 minutes.

It was observed that the breakdown voltage is approximately ~1KV which is in good agreement with the applications for which the device is used (~40V). It is observed that the breakdown strength decreases with cleaning of the device (ref Fig 3) if one uses contaminated cleaning solvent.

This may be attributed to residue deposited during cleaning. One probable technique to boost the breakdown voltage after cleaning is by rinsing in a neutralizing reagent.

These observations are concurrent with the breakdown strength of Pin2-Body and Pin3-Body.

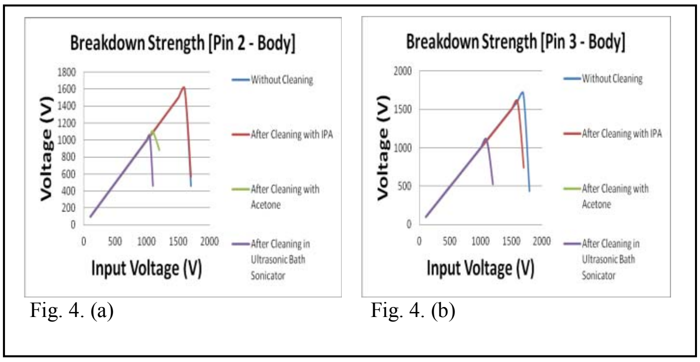

Fig.4.*Breakdown strength Pin2-Body(a), Breakdown strength Pin3- Body (b)*

V. Breakdown Strength Pin- Pin

The Pin to pin breakdown strength was observed using the same set up, where two leads were connected to two different pins alternatively.

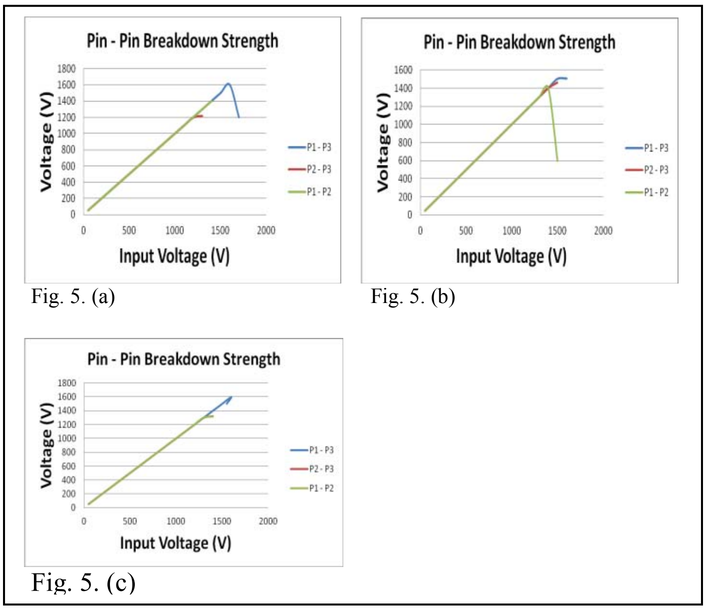

Fig. 5. *Pin to pin breakdown strength without cleaning (a), Pin to pin breakdown strength after cleaning with IPA (b), Pin to pin breakdown strength after cleaning in Ultrasonic bath sonicator (c).*

The observation is that the 3 pins are having high breakdown voltage (in range from 1.100kV to 1.800kV ref. fig.5(a)).

At the points of failure we can see sparking at the metal-glass interface surface. The high voltage (in kilovolts) can be compared to the ionization potential of air ~3kV / mm.
Note: Experimentally the arching is found to take place between pin to pin outside the metal casing at high voltages beyond 1kV.

VI. Insulation Resistance test

For the Insulation resistance test, the specimen was subjected to DC voltage in increments of 50V from 50V to 1kV. The rise time was set to 01.00s.
Note: Maximum Insulation resistance : 9999 M ohms

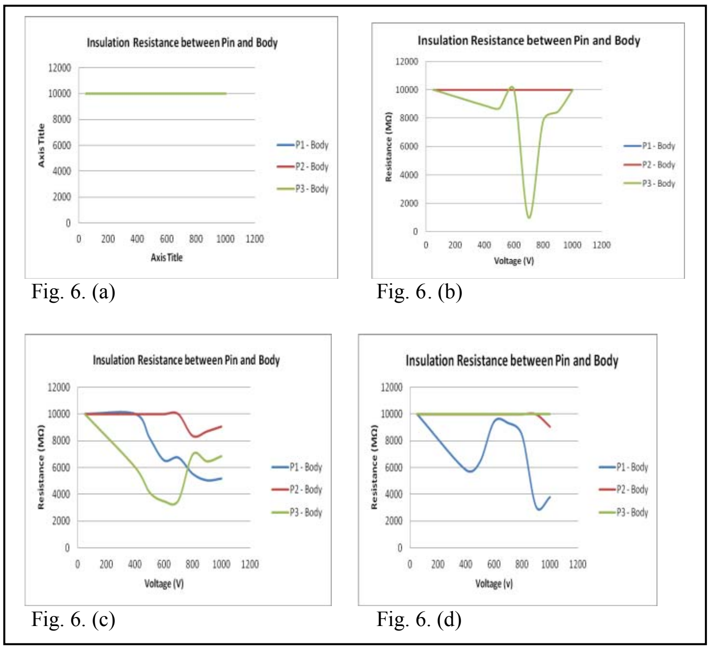

Fig. 6. *Insulation resistance between pins and body without cleaning (a), body after cleaning with IPA (b), after cleaning with Acetone (c), after cleaning in Ultrasonic bath sonicator (d).*

As observed this high insulation resistance is in good agreement with the expected values of Glass-Metal interface in the order of few giga ohms. This holds true in all conditions of the TO -254 Package.
Note: In fig. 6.(a) all the three curves are overlapping .

VII. Hermetic Seal

Helium Leak test is the most widely used and highly reliable test to find the extent to which the device is hermetically sealed. The TO-254 package was exposed to helium leak test. With Min detectable leak rate (Sniffing) as 1-10e(-8) Pa m^3 /s and Min detectable leak rate (Vacuum) as 1-10e(-13) Pa m^3 /s and a factor of safety as 2, we get the Lifetime of the device on exposure to leak as 1.4e(9) s or **44.4180 years**.

This high lifetime of the device indicates that for all practical purposes it can be considered reasonably inert to gas leaks (Hermetically Sealed : Airtight).

VIII. High Temperature Analysis

It is quite unrealistic to expect the device to operate only in standard room temperature. In the aircrafts, in automobile engine assembly and drive-trains are just few examples where the packaging would be employed for Si, SiC, and/or GaN devices. In such high temperatures, it is critical for the device to function with minimum deviation, and there is a need to understand and model this change in behavior mathematically to design suitable compensation techniques.
The same breakdown test cycle was repeated by heating the device to 453K (180°C).

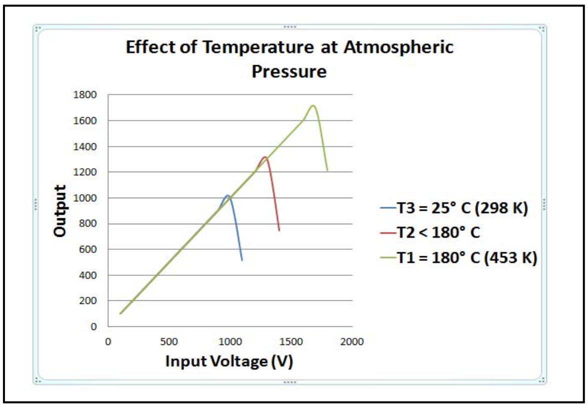

Fig. 7. *Effect of Temperature at Atmospheric Pressure*

The observations are noted in the proceeding section.

IX. Vacuum Analysis

The vacuum environment was set up using rotary vacuum pump. A pressure of 10e(-2) torr was established inside a glass vacuum chamber.

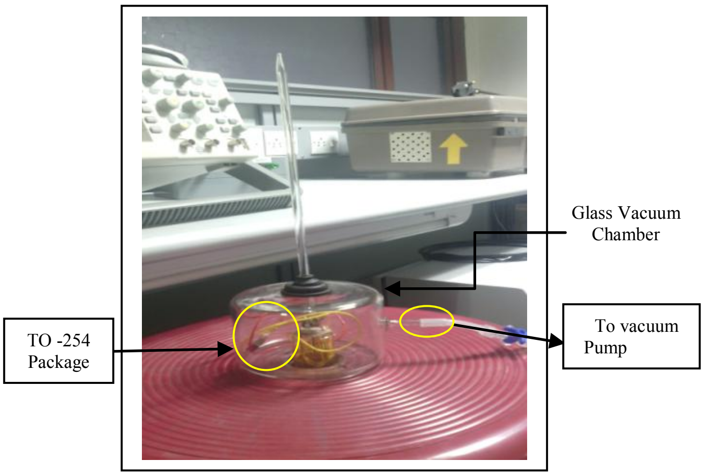

Fig. 8. Glass *Vacuum Setup*

The TO 254 was placed in a glass Vacuum Chamber and vacuum was created using rotary vacuum pump (Pressure 10^(-2) torr).
The two leads for breakdown tester were connected to Pin3 and body. Voltage was incremented in steps of 100V and Insulation Resistance was tested.

It was observed that while the experiment was regulated, if the device breaks down in vacuum, then the pressure is increased to atmospheric pressure (750 torr), no breakdown was observed. Keeping all other parameters constant.

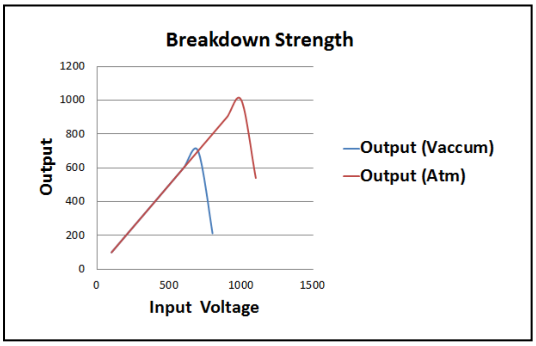

Fig. 9. *Effect of Vacuum on Breakdown Strength*

It is understood that this decrease in breakdown strength (ref. Fig.9) in vacuum was not due to any changes in the TO-254 specimen, but due to Townsend discharge, which was analyzed using two bare isolated leads in same vacuum environment. It is hence advisable to seal with any inert gas (Ar) to ensure no suppression in breakdown strength.

X. Combined Analysis of Temperature and Pressure

This analysis deals with combined effects of temperature and pressure on the TO configured packaging.

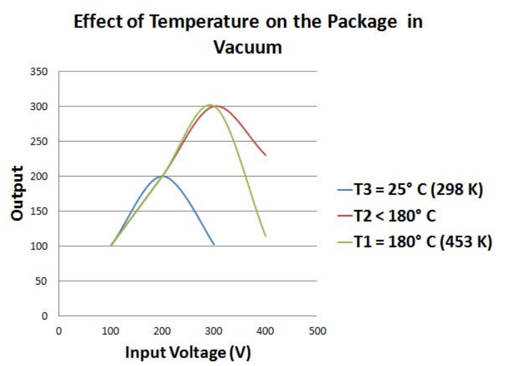

Fig. 10. *(a)*

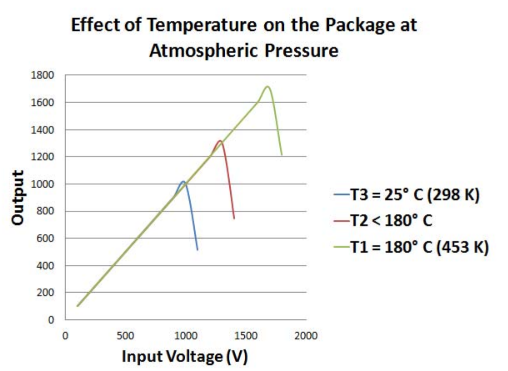

Fig. 10. *(b)*

Fig. 10. *Effect of Temperature in Vacuum (a), Effect of Temperature at atmospheric pressure (b)*

With the increase in temperature (ref. Fig. 10.(a)), the breakdown voltage is found to increase by around 63% at atmospheric pressure. With the increase in temperature (ref. Fig. 10.(b)), the breakdown voltage is found to increase by around 33% in vacuum.

XI. Scanning Electron Microscope Analysis

Observations under the Scanning Electron Microscope (SEM) provide considerable insights into the behavior and response of the device in the above environments. Images were taken before conduction of the experiments and after the cycles (device being subjected to much strain and stress and extensive sparking at breakdown voltages). These are observed at an angle of tilt = 24.4°.

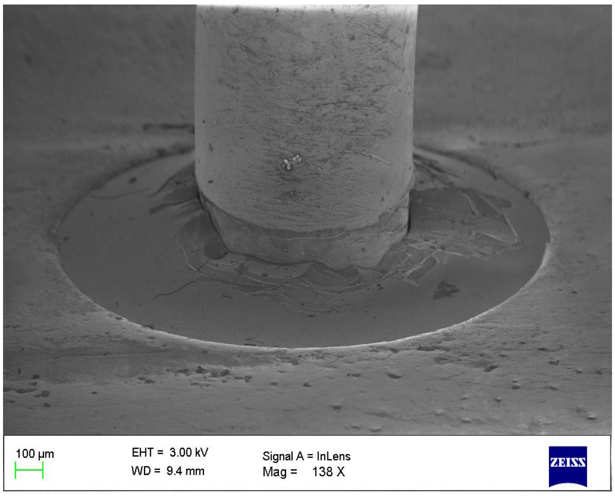

Fig. 11. (a)

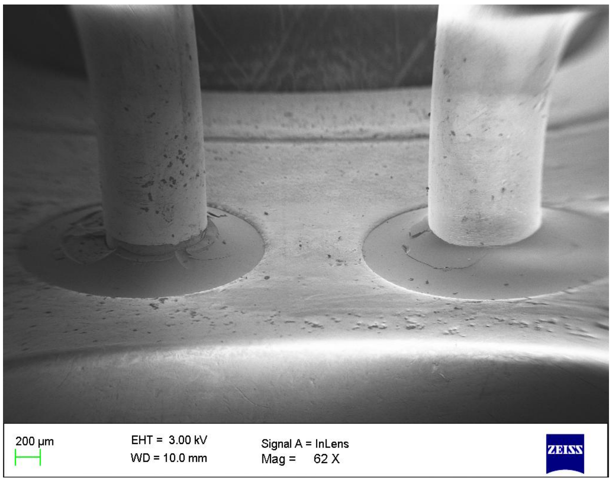

Fig.11. (b)

Fig. 11. *SEM Images of Pin 1(a); Pin 1 and Pin 2 from bottom(b).*

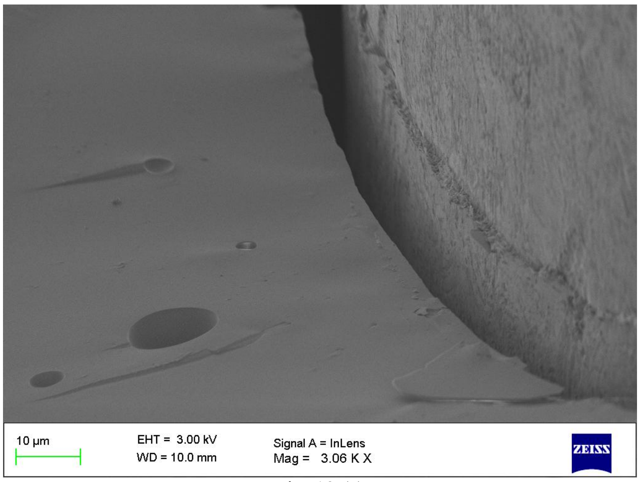

Fig. 12.(a)

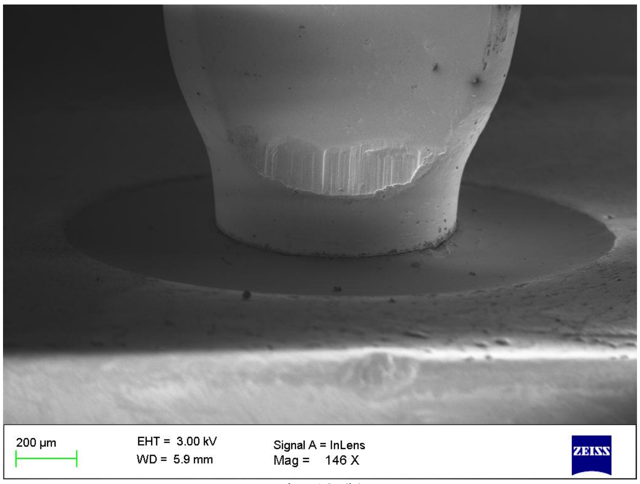

Fig. 12.(b)

Fig. 12. *SEM image of Pin 3 from bottom (a), SEM image of Pin 2 from top(b).*

At the glass-metal interface surface on the periphery of the contact leads, we find some deformations (ref. fig.11.(a)), which can broadly be attributed to the stress. We also find erosion in the coatings of the contact leads (ref fig.11.(a) and fig.12.(a)). This is reasoned out to be an effect of sparking which also explains the absence of such effects in the interior of the package (ref. fig.12.(b)).

Fig.11.(b) illustrates that pin 2 (to the left) has relatively less deformed glass-metal interface surface and Its breakdown strength is better than that of pin 1 as exhibited in Fig. 3 and Fig. 4. We also predict that these deformities and erosion (fig.12.(b)) will lead to an increase in the leak rate and hence a reduction in the lifespan from the experimentally ascertained 44.4180 yrs.

XII. Conclusion

On observing the electronic properties of the device; These experiments substantiate the use of TO-254 Package for Semiconductor Power device based systems in specific and all electronic circuit packaging in general. Without loss of generality these trends can be extended to most if not all packages of TO type. Having established the bounds experimentally, we now have a metric to choose the specifics. Our model specifies Vacuum lowers the Breakdown Voltage of the device than at atmospheric pressure for a constant temperature. Cleaning without after-procedures lowers the Breakdown Voltage of the device for a constant Temperature. With the increase in temperature, the Breakdown Voltage increases at atmospheric pressure and in vacuum.

Acknowledgment

We would like to acknowledge the Centre for Nano Science and Engineering (CeNSE), Packaging Team and Micro and Nano Characterization Facility (MNCF) at IISc for their wholehearted support and assistance.

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