Droplet Lab

The Practical Guide to Surface Science for the Semiconductors Industry

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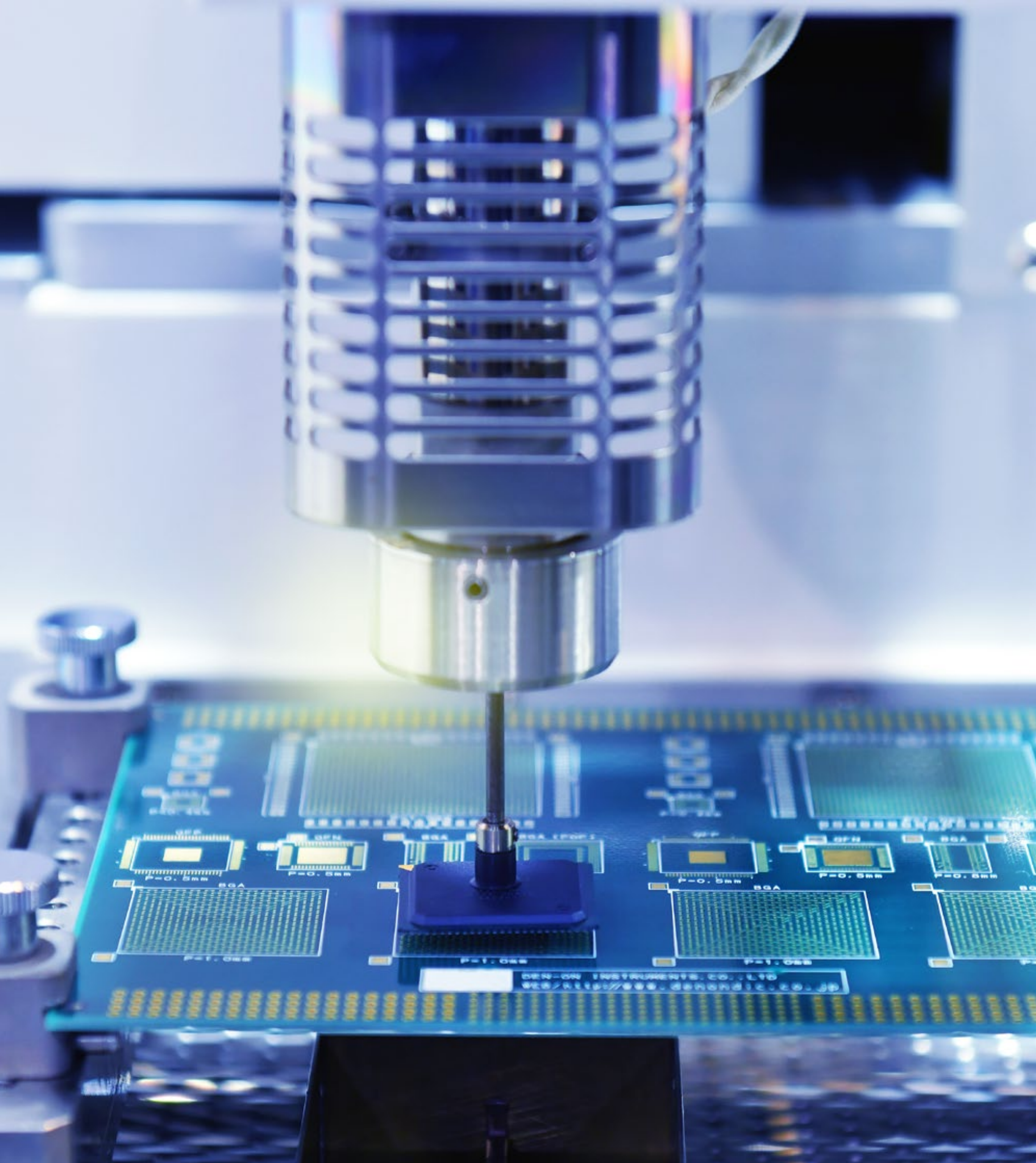

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INTRODUCTION

In the field of semiconductor manufacturing, achieving best performance and refining processes is the main challenge in this industry. The influence of surface properties is sometimes underestimated but they play very important role in optimizing the performances. These measurements provide valuable insights into material properties, processes, and device performance, ultimately contributing to:

Enhanced Product Quality

Customized Material Properties

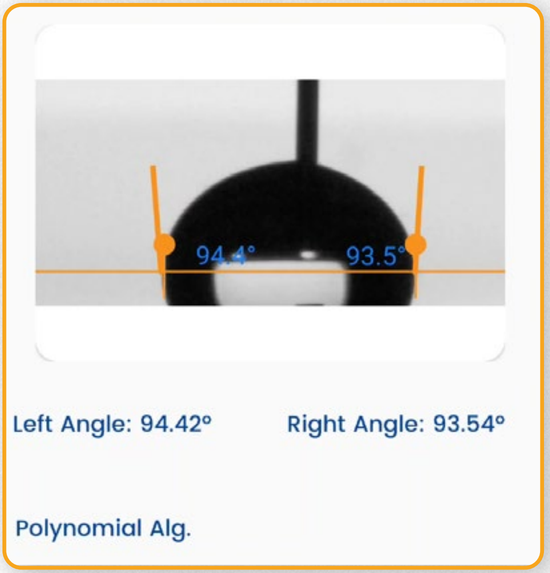
Compliance with Industry Standards

Improved Yield Rates

Some of the important surface properties that are used to understand the behavior of semiconductor and for their quality improvement are:

Contact Angle Measurement

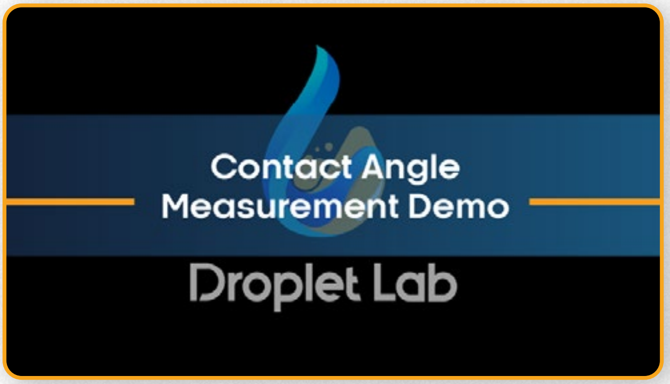
Contact angle quantifies the wettability of a surface, representing the angle between the surface of a liquid and a solid surface. Drop shape analysis by contact angle determination of sessile drops has been shown to be the preferred method to characterize solid surfaces in terms of wetting behavior [1]. In 3D semiconductor packaging, wafer bonding is a critical process. Controlling the contact angle between the wafers and the bonding material is essential to ensure uniform bonding interfaces and prevent void formation. By measuring the contact angle, manufacturers can fine-tune the bonding conditions, such as temperature and pressure, to achieve optimal bonding strength and reliability.



Sample Image taken from Droplet Lab Tensiometer

Droplet Lab offers both Young-laplace and Polynomial methods in our Tensiometer.

Young - Laplace Method	Polynomial Method
Uses the whole drop profile to calculate the contact angle value	Uses only a certain percentage of the drop profile to calculate the contact angle value.
Only compatible with an axisymmetric drop. This is not always seen in practice, as a needle is typically inserted into the drop to increase/decrease the drop volume.	Compatible with both axisymmetric and non-axisymmetric drops.
Measurement results are more consistent compared to the polynomial fitting method.	Measurement results are less consistent, as they are affected by local surface imperfections.



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Learn how Contact Angle measurement is done on our Tensiometer

Dynamic Contact Angle

Ideally, when a drop is placed on a solid surface, a unique angle exists between the liquid and the solid surface. The value of this ideal contact angle (the so-called Young's contact angle) can be calculated using Young's equation.

In practice, due to the surface geometry, roughness, heterogeneity, contamination, and deformation, the value of the contact angle on a surface is not necessarily a unique value but falls in a range. The upper and lower limits of this range are called the advancing contact angle and the receding contact angle, respectively.

The value of Advancing and receding for a solid surface is also very sensitive and can be affected by many parameters, e.g., temperature, humidity, homogeneity, and minute contamination of the surface and liquid. For example, the advancing and receding contact angles of a surface at different locations can be different.

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[Learn how Dynamic Contact Angle measurement is done on our Tensiometer]

Dynamic Contact Angle versus Static Contact Angle

Practical surfaces and coatings naturally show contact angle hysteresis, indicating a range of equilibrium values. Measuring static contact angles provides a single value within this range. Solely relying on static measurements poses problems, like poor repeatability and incomplete surface assessment regarding adhesion, cleanliness, roughness, and homogeneity.

Practical applications require understanding a surface's liquid spreading ease (advancing angle) and removal ease (receding angle), such as in painting and cleaning. Measuring advancing and receding angles offers a holistic view of liquid-solid interaction, unlike static measurements, which yield an arbitrary value within the range.

This insight is crucial for real-world surfaces with variations, roughness, and dynamics, aiding industries like semiconductors, materials science, and biotechnology in designing effective surfaces and optimizing processes.

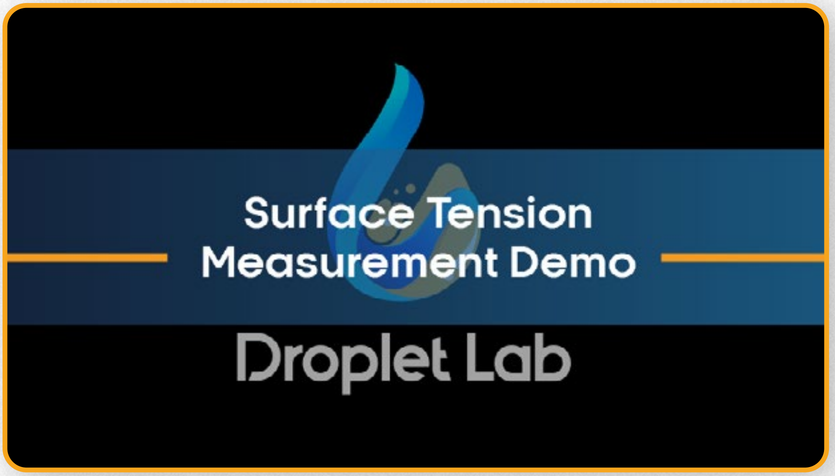
To improve the data quality of your contact angle measurements we recommend you read up on the best practices in the below referenced paper.

Guidelines to measurements of reproducible contact angles using a sessile-drop technique

Surface Tension Measurement

This property measures the force acting on the surface of a liquid, aiming to minimize its surface area. [2] Surface tension plays a role in wetting and etching processes. During etching, achieving uniform material removal across a wafer is crucial. By understanding and manipulating surface tension, manufacturers can design etching solutions that wet the surface evenly, resulting in consistent etch profiles. This leads to improved process repeatability and higher device yield.

Sample Image taken from Droplet Lab Tensiometer



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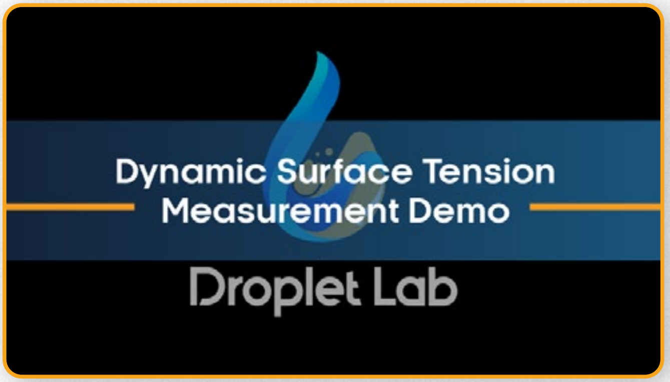
Dynamic Surface Tension

Dynamic surface tension is different from static surface tension, which refers to the surface energy per unit area (or force acting per unit length along the edge of a liquid surface).

Static surface tension characterizes the equilibrium state of the liquid interface, while dynamic surface tension takes into account the kinetics of changes at the interface. These changes could be the presence of surfactants, additives, or temperature, pressure, and/or compositional changes at the interface.



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Learn how dynamic surface tension measurement is done on our Tensiometer

When to use Dynamic Surface Tension Measurement

Dynamic surface tension is particularly important when dealing with processes that involve rapid changes at the liquid-gas or liquid-liquid interface, such as droplet and bubble formation or coalescence (change of surface area), behavior of foams, and drying of paints (change of composition, e.g. evaporation of solvent). It is measured by analyzing the shape of a hanging droplet over time.

Dynamic surface tension has applications in various industries, including semiconductors, coating, pharmaceuticals, cosmetics, food and beverage, and industrial processes where understanding and controlling the behavior of liquid interfaces is essential for product quality and process efficiency.

Scientific Validation of our Instrument:

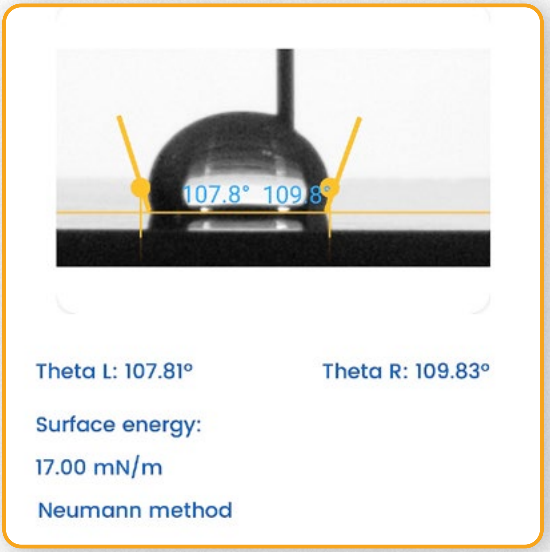
Accuracy and reliability are the cornerstones of any scientific instrument, and concerns regarding the precision of our setup are both understood and acknowledged. While our state-of-the-art tech lays the foundation, it's our unwavering commitment to validation that sets us apart.

This promise of transparency and scientific rigor is supported by two peer-reviewed papers that thoroughly detail and validate the performance of our instrument:

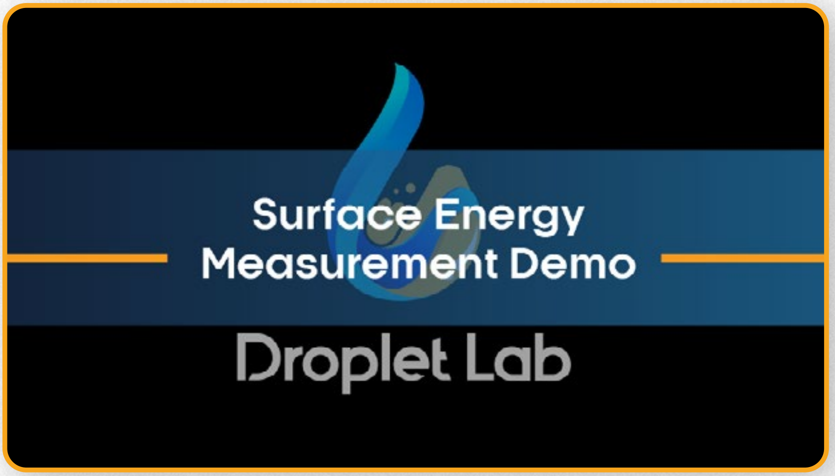
1. Review of Scientific Instruments
2. Colloids & Surfaces A

Surface Energy Measurement

Surface energy refers to the energy required to create a unit area of a new surface [3]. Contaminants on semiconductor surfaces can negatively impact device performance. Surface energy measurements guide the selection of cleaning agents and processes. By choosing cleaning agents with appropriate surface energy properties, manufacturers can ensure effective removal of contaminants without damaging sensitive surfaces. This is particularly important in critical areas such as microelectromechanical systems (MEMS) and microfluidic devices, where cleanliness is crucial for proper functionality.



Sample Image taken from Droplet Lab Tensiometer



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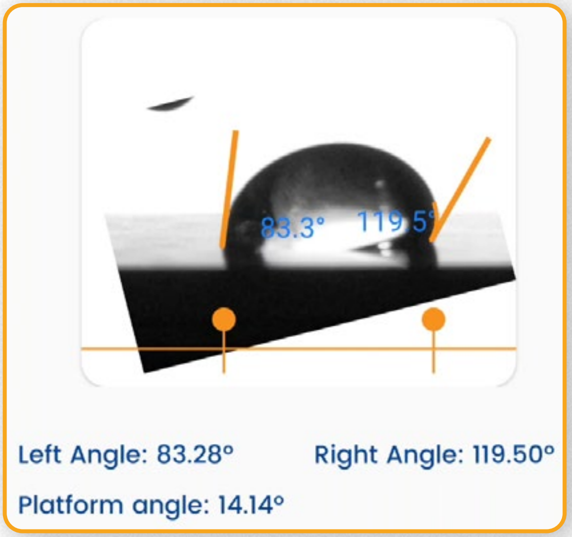
[Learn how Surface Energy measurement is done on our Tensiometer]

Sliding Angle Measurement

The sliding angle measures the angle at which a liquid film slides over a solid surface. It is commonly employed to assess the slip resistance of a surface. During chip packaging, adhesive materials are used to bond the semiconductor die to the package. However, adhesive residue can compromise device reliability. By measuring and controlling the sliding angle of the packaging material, manufacturers can ensure that liquid adhesives slide off cleanly, leaving minimal residue. This optimization minimizes the risk of shorts, improves electrical performance, and increases the overall reliability of the packaged devices.



Sample Image taken from
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[Learn How Sliding Angle Measurement is done on our Tensiometer]

By carefully considering and measuring these surface properties, Semiconductor manufacturers can continually improve their products' quality and meet the evolving needs of their customers.

Real-World Implications
Case Studies

Within the Semiconductor industry, several case studies exemplify the advantages derived from conducting surface property measurements.

Presented below are a few illustrative instances:

1 Photoresist Adhesion in Lithography

Scenario: Within the domain of photolithography, the art of meticulous pattern creation serves as the key to manufacturing complex semiconductor devices. This relies on the delicate interplay between the photoresist and the substrate. The photoresist adhesion onto the substrate acts as a linchpin, determining the sharpness and precision of the resultant patterns. A strategic approach involves delving into the surface science of properties.

Application: By examining the substrate's surface energy and analyzing the contact angle exhibited by the photoresist, manufacturers gain insights to tune the adjustments. This refining process enhances adhesion properties, ultimately translating into a seamless pattern transfer. The outcomes are manifold, including enhanced yields, sharper results, and a visible reduction in defects during the lithography journey.

2 Reducing Adhesive Residue in Packaging

Scenario: In the complex chip packaging process, adhesive materials are key, binding the semiconductor die to its protective package. Yet, there's a big challenge in the form of adhesive residue that can cast shadows over device reliability.

Application: To avoid this, the manufacturer is involved in measuring and meticulously managing the sliding angle of the packaging material. This careful step guarantees that liquid adhesives elegantly glide away without leaving behind a trace. This optimization translates into a twofold advantage: first, it significantly reduces the odds of any shorts or unwanted connections, and second, it effectively boosts the electrical performance of the device.

3 Managing Receding Meniscus in Immersion Lithography

Scenario: For effective immersion lithography process, successful management of the immersion fluid is needed. Receding meniscus event which will result in residual liquid left on the wafer in the form of a thin film or droplets is a major failure mechanism. It is desired that the immersion fluid is confined to a region near the lens and allows the wafer to scan under the lens during exposure.

Application: The Meniscus failure mechanism has not been entirely clear to a Semiconductor manufacturer and therefore was a big hurdle for successful implementation of immersion lithography. They approached a laboratory for the solution and the scientist, understanding the importance of the surface forces in drainage and pattern collapse in lithography, developed a fluid formulation. The new rinsing formulation had proper surface tension characteristics that facilitated proper drainage of liquid.

We are your partners all the way in solving your Business & Technological challenges

If you are interested in implementing these or any other applications you can send an email to us at
abhandankar@dropletlab.com

We would also be interested to hear from you if you face any sample related difficulties. Book a call with our engineer to discuss the same with the below link
https://calendly.com/gsaini-ob4

Standards and Guidelines

- **ASTM D1331-14: - Standard Test Methods for Surface and Interfacial Tension of Solutions of Paints, Solvents, Solutions of Surface-Active Agents, and Related Materials:**

  In ULSI fabrication the particle contamination on silicon wafer can impact the final yield badly. To suppress particle surfactants can be added [4]. In this regard, D1331-14 covers the guidelines to evaluate the effectiveness of surface active agents in reducing surface tension [5]. This method also helps in predicting the interactions between liquids and solid surfaces that can be used to establish wetting properties.

- **ASTM D7490-13(2022): - Standard Test Method for Measurement of the Surface Tension of Solid Coatings, Substrates and Pigments using Contact Angle Measurements**

  Silicon wafers with hydrophobic surfaces can be bonded at room temperature (RT) with the help of a dip in diluted HF and that becomes possible due to Dispersion van der Waals forces [6]. D7490-13 standard takes the help the concept that total free energy at a surface is the sum of contributions from different intermolecular forces, such as dispersion, polar and hydrogen bonding. This test method provides a procedure to calculate the surface properties like surface tension and its dispersion and polar components of the solid [7].

Sources

[1] “Statistical Contact Angle Analyses with the High-Precision Drop Shape Analysis (HPDSA) Approach: Basic Principles and Applications”, Coatings 2016, 6(4), 57; https://doi.org/10.3390/coatings6040057.

[2] “Surface tension and its role for vertical wet etching of silicon”, J. Micromech. Microeng. 22 (2012) 125012 (7pp). doi:10.1088/0960-1317/22/12/125012.

[3] “Surface free energy of solids by contact angle measurements”, J. Sci. Technol. Appl., 2 (2017) 84-93. https://doi.org/10.34294/j.jsta.17.2.17 | ISSN 0719-8647.

[4] “Effect of surfactant on removal of particle contamination on Si wafers in ULSI”, Trans. Nonferrous Met. SOC. China 16(2006) s195-sl98.

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[6] “Hydrophobic silicon wafer bonding”, Appl. Phys. Lett. 64 (5), pp. 625-627, 31 January 1994.

[7] https://www.astm.org/d7490-13r22.html.