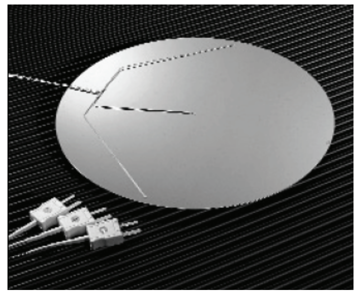
KLA-Tencor
Accelerating Yield

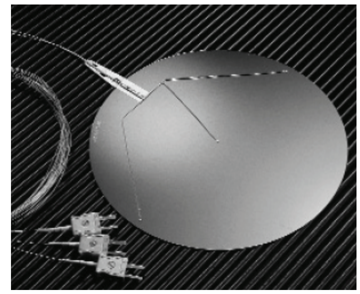
Application Note

SAN00 4

1605 to 1630 Process Probe Instrumented Wafer Conversion for WJ Furnace

This Application Note details KLA-Tencor's SensArray Division'S recommendations for converting from Process Probe 1605 to 1630 Instrument Wafers for Temperature Profiling of Watkins-Johnson Thermal CVD Oxide Systems.


Process Probe 1605


Process Probe 1630

BACKGROUND

In 1992 SensArray® introduced the Process Probe® 1605 thermocouple (TC) instrumented wafers for profiling deposition temperature in Watkins-Johnson belt CVD oxide deposition systems. With Watkins-Johnson's introduction of TEOS based deposition chemistry for BPTEOS oxides, deposition temperature control became more critical, increasing the dependence on frequent and accurate temperature profiling to maintain a tight process temperature window. In fab use with typical procedures, the 1605 wafer has not satisfied most users' needs for temperature measurement accuracy and reliability.

With assistance from Watkins-Johnson, SensArray evaluated typical fab TC wafer profiling practices. Based on these evaluations, SensArray improved the 1605 wafer packaging and Watkins-Johnson produced a videotape of TC wafer handling guidelines. While some users benefited, these changes were not sufficient to solve many of the accuracy and reliability problems encountered in the field. In 1996, SensArray re-evaluated the 1605's design and material limitations, as well as requirements for pre-shipment testing and qualifications of TC wafers. The Process Probe 1630 instrumented wafer was conceived and developed in 1997 to solve many of the limitations of the 1605.

OVERVIEW

The standard configuration for 1605 and 1630 TC instrumented wafers has metal sheathed Chromel-Alumel (type K) thermocouples securely attached to the wafer with metal rivets. Temperature measurement accuracy and response time is provided by isolating the thermocouple junction from the metal sheath. The thermocouple wires extend from the sheath above the wafer down to the TC measurement junction bonded into a cavity.

The welded measurement junction is bonded into the wafer by forming a blind cavity, with re-entrant walls, in the wafer to contain the thermocouple junction. High-temperature ceramic cement, composed of SiO_2 and Al_2O_3, encapsulates the junction and thermally bonds it to the substrate. The ceramic also provides electrical isolation from the substrate and prevents chemical reaction between the thermocouple and silicon which could degrade the thermocouple. The ceramic cement's coefficient of thermal expansion matches silicon's, thus maintaining thermal contact between the TC junction and silicon over the full operating temperature range. The new Process Probe 1630 thermocouple instrumented wafer includes improvements in design, materials, and functional testing. Field testing has shown that the 1630 benefits users with significantly improved reliability, accuracy, and ease of use compared to the 1605. Improvements in the TC sheath materials, have significantly reduced the frequency of early life TC failures. Braiding of the sheathed TC leads prior to shipment eliminates the need for field braiding and the risk of potential damage to the TC wafer.

The new ThermaBond™ Sensor design improves heat transfer between the silicon wafer and TC sensor, increasing accuracy and measurement stability–especially when measuring temperatures beneath the injectors. A number of differences may be observed when converting from the 1605 to the 1630 due to the reduced sensitivity of its ThermaBond structure to measurement errors related to vertical temperature gradients encountered when profiling WJ Systems. They include:

- Smoother thermal response curves are recorded when the 1630's measurement TCs pass under the system's injectors. This is from reduced TC junction sensitivity to the high velocity nitrogen flow cooling the TC wires above the wafer, near the TC bond.
- More accurate indication of true silicon wafer temperature. Higher process temperatures of from 5 to 10 degrees Celsius are normally indicated by 1630 wafers, when compared to readings obtained from 1605 wafers.
- CAUTION: Process recipe temperatures may need to be changed to reflect this calibration improvement in displaying true silicon temperature.

STRUCTURE OF 1630 AND 1605 WAFERS

Both Process Probe 1630 and 1605 wafer designs have consisted of a silicon wafer in which a number of TC's (typically three) are embedded. The lead system extends three (3) meters from the wafer allowing full profiling of the WJ System's deposition zones. The lead system consists of individual sheathed metal thermocouples. Each metal sheathed TC is manufactured in one piece from the thermocouple junction to the connector. Near the edge of the wafer, the sheath cables are bundled in a stainless steel metal stress relief clamp assembly that securely attaches the thermocouples to the wafer and prevents lead movement on the wafer which would stress or break the TC junction or bond to the wafer.

SHEATH CABLE MATERIAL CHANGES

The sheath cable has an outer diameter of 0.5 mm. It consists of an outer metal sheath and inner thermocouple conductors, insulated with MgO. In the 1605 product, the outer sheath metal is 304 stainless steel, whereas with the 1630 product, the outer sheath metal has been changed to Inconel® 600. The thermocouple inner conductors are type-K (NiCr vs. NiAlSi). The diameter of the conductors is approx. 0.1 mm.

The manufacturing process of the sheath cable ensures that the MgO has a high compaction ratio and maintains isolation of each lead through the full thermal profiling cycle. The use of an Inconel sheath cable has significantly improved the reliability and lifetime of 1630 wafers, compared to 1605 wafers.

Application Note

SAN00 4

1605 to 1630 Process Probe Instrumented Wafer Conversion for WJ Furnace

When the sheath metal is 304 stainless steel as in the 1605 product, early failures of the thermocouple may occur after a limited number of thermal profiling cycles. These failures may be related to the difference in thermal expansion between the stainless steel and the thermocouple wires. Inconel sheath used in the 1630, is a Ni alloy and has a thermal coefficient of expansion that is closer to the valuesfor the type K thermocouple materials (also Ni alloys).

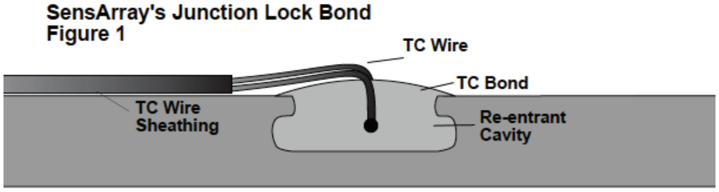
STRESS RELIEF & LEAD SUPPORT STRUCTURES

Near the edge of the wafer, the sheathed cables are clamped within a metal stress relief assembly. This serves to keep the sheaths down near the wafer surface, ensuring that the leads will not be caught under the limited clearance area beneath the injectors. The 1630 also includes a stainless steel foil “tail” to provide support to the leads near the wafer edge and beyond the wafer edge in a zone where conductor breakage has frequently occurred in 1605 wafers. When either the 1605 or 1630 wafer is placed on the belt, care should be taken that the wafer is resting fully flat on the belt. If the edge of the wafer is lifted above the belt surface by bent leads pushing down on the belt, the wafer may hang up and slide on the belt when passing under an injector. Also, the temperature indicated by one or more of the thermocouples will be lower than the process temperature due to poor heat transfer from the belt— reducing accuracy of the thermal profile data and causing concern that the TC calibration has shifted, when the origin of the problem is poor thermal contact with the belt.

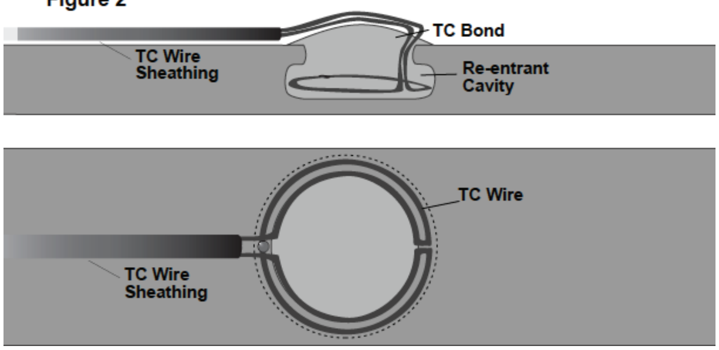
THERMOCOUPLE JUNCTIONS AND BONDING TO SILICON

At one end of the sheath cable (over the wafer surface), the sheath is removed and the inner thermocouple wires are extended and joined to form a thermocouple junction. The thermocouple is mounted in a cavity in the silicon wafer. In the obsolete 1605 product, the mounting of the thermocouples used a ceramic cement to bond the junction directly into the center of a cylindrical cavity. The cavity’s reentrant walls mechanically retained the ceramic and TC junction. At higher temperatures, this structure is sensitive to a vertical heat flux which is significant under the WJ System’s injectors.

Process Probe 1605
SensArray's Junction Lock Bond
Figure 1



Process Probe 1630
SensArray's ThermaBond™
Figure 2



In the 1630 product, an improved method is used for mounting the thermocouple in the cavity, similar to the method used in SensArray’s 1530 TC wafer products. The 1630’s ThermaBond, provides a much longer thermocouple wire path length within the bond, and the TC junction is more deeply embedded in the re-entrant area of the cavity as shown in Figure 2. This reduces the heat leak along the TC wires and it also places the TC’s junction closer to the silicon in an area where the bonding cement has very low thermal gradients. SensArray Application Note 003 (SAN003) details the advantages of the 1530 bond over the 1501 bond for RTP applications and proves that the 1530 type bond used in the 1630 is more accurate and has a better stability for high temperature measurements.

In the most commonly used sensor configurations, a 1630 wafer has three thermocouple positions: left edge, center, and right edge when referenced to a wafer notch or flat. The left and right sensors are typically located 6mm from the edge of the wafer.

USING 1630S TO PROFILE WJ CVD SYSTEMS

Proceed by removing the 1630 wafer from its shipping packaging. Carefully straighten the leads without bending the leads near the wafer. This is most easily done by two people where one person places the wafer on a flat surface and carefully holds the leads near the wafer to prevent bending them, while the second person uncoils the leads and straightens them. Verify the leads are straight as they exit the wafer—be sure they do not bend in a downward direction. This can be assured by carefully straightening the sheathed leads in a line parallel to the plane of the wafer.

The metal sheathed TC leads and their attachment to the wafer are extremely rugged. Pulling on the leads to remove the wafer from a belt furnace may be done if care is used. The wafer must not snag or get caught during travel through the furnace or removal from it.

Care must be used to prevent tight bends on the leads. Bend radius should be at least six inches or greater. Repeated lead flexing at tight bends may result in cracking and fracture of the metal sheath or TC leads within it. While the lead system is very rugged, the bare TC leads on the surface of the wafer are very fragile. Touching or movement of the metal sheath or TC wires between the attaching rivets and junction bond to the wafer must be avoided. Damage is highly probable if the wafer is allowed to rest on the thermocouple ceramic bonded junctions. Use and store the wafer only when resting on the side opposite the junctions. If damage is suspected, field inspection of the junction bond should be done optically with a 15 to 40 power microscope. Look for fracture of the ceramic, or separation of the thermocouple junction from the wafer. Do not test the ceramic bond’s integrity by moving the wire, as this will usually result in damage to the ceramic.

Verify that inert gas only is flowing in the system and that there has been enough time to purge the system of reactive gasses. Set the gas flow rate for profiling. Place the wafer flat on the belt. Care must be taken not to bend

Application Note

SAN00 4

1605 to 1630 Process Probe Instrumented Wafer Conversion for WJ Furnace

the sheath TC too much near the stress relief and tail assembly which may reduce the TC wafer's life. When the belt moves the wafer into the furnace, the TC leads must be carefully fed into the oven in a straight line to prevent wafer slippage or lateral movement on the belt. While the wafer is moving through the furnace, the temperature of the sensors is recorded, producing the thermal profile.

When the wafer has passed through the profile region, slowly withdraw it by gently pulling on the sheathed leads at a rate not to exceed 33 inches per minute and a cooling rate not to exceed 30°C per second. Longer functional life of a 1630 wafer has been obtained when not exceeding these withdrawal rate guidelines. The most critical region to control withdrawal is the last 24 inches inside the system nearest the belt entrance (wafer exit point from the system when withdrawn).

When storing the TC wafer be sure not to coil the leads in a coil smaller than 12 inches in diameter. Be sure to keep the leads straight within 6 inches of the wafer edge. The temperature range of the 1630 wafers is 0-800°C.

Above 400°C, the type K thermocouples should only be used in an inert oxygen-free ambient environment (N_2, with less than 10 ppm O_2). Thermocouple wafers should not be used in a process gas environment (e.g. CVD precursors).

LEAD CONNECTIONS

Process Probe 1630 Instrumented Wafers are normally supplied with a subminiature, type K, flat blade male plug. If extension leads are used between the plugs andmeasurement instrument, make sure to use only type K (Chromel-Alumel) extension lead wire and connectors. This will reduce risk of secondary thermoelectric junctions that can be a source of measurement errors.

WAFER CLEANING

Do not allow the wafer to become contaminated or dirty. Keep free of particulates by gently spraying with nitrogen gas. Cleaning is not normally recommended. If absolutely necessary, the wafer can be wiped with a D.I. water dampened, lint free, clean room type wipe. Do not touch any portion of the thermocouple assembly or allow the ceramic to contact water. Use only D.I. water, under nocircumstances use any solvent.

MEASUREMENT UNCERTAINTY OF 1630 WAFERS IN THE BELT FURNACE APPLICATION

The measurement uncertainty (offset of the indicated temperature compared to the undisturbed silicon wafer's temperature) consists of a number of factors:

- the offset of the TC wire's millivolt output compared to the NIST (ITS 90) standard for type K wire
- drift of the TC wire response due to drift of the TC wire's output voltage calibration
- the offset between the TC's junction temperature and the undisturbed silicon wafer temperature
- offset due to differences between the infrared optical properties of the instrumented wafer and the product wafer
- instrumentation errors of the type K readout, strip chart recorder or data acquisition system

The type K thermocouple wire used in the construction of the Process Probe 1630 is classified as "special limits" wire. With a maximum absolute temperature calibration error limit of 0.4%, each lot is certified to meet NIST standards by fabricating and testing sample thermocouples from sheathed wire samples taken at numerous points within each wire lot. TC-to-TC calibration variations within the lot are typically <0.2°C.

The offset of TC wire, compared to NIST Standard ITS 90, is measured by calibrating it in an isothermal furnace, and comparing its output to a reference thermocouple which has been calibrated to NIST traceable standards. Using such a calibration method, a NIST traceable temperature reading can be obtained that is valid in an isothermal ambient. For a K-type TC, the accuracy of such a calibration table can typically be guaranteed to be traceable to the NIST ITS90 standard with an uncertainty of ±1°C or better. TC wire calibration data with certification is supplied with each 1630 wafer. The data is provided for certain fixed temperature calibration points which were determined from a sample of wire from the same sheathed TC wire lot used to construct that 1630's TCs.

TC CALIBRATION

Since thermocouples do not generate their output voltage at the junction, but along the TC wire where it passes through thermal gradients, the preservation of the metal alloy's composition uniformity where thermal gradient are present is critical to maintaining TC calibration. Oxidation of the TC wires is the most likely cause of shift in alloy composition of the TC wire and thus, its calibration. Almost all the thermocouple wire is well protected inside the sheath, so oxidation is only probable above the surface of the wafer near the TC bond. Accurately determining the shift in calibration is difficult because its measurement requires a tightly controlled vertical thermal gradient above the wafer with the same magnitude and slope as encountered in profiling the WJ System. This is very difficult to achieve in a calibration verification system.

KLA-TENCOR CORPORATION
One Technology Drive
Milpitas, CA 95035
phone +1 408 875 3000
www.kla-tencor.com