

# The CMP Slurry In-line Process Monitor -**Specification**

### **Abstract**

Provides a detailed technical specification for the CMP Slurry In-line Monitor.

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### **1** Overview – The CMP Slurry Monitor

Colloidal Dynamics has developed the Chemical Mechanical Polishing (CMP) Slurry Monitor for the in-line monitoring of the particle size, zeta potential, and weight percent solids of CMP slurries. The CMP Slurry monitor is used in advanced semiconductor manufacturing. The product is also used for pilot plant and on-line applications outside the semiconductor industry.

The CMP Slurry Monitor has been designed to measure slurry characteristics using in-line sensors deployed in a Slurry Distribution System (SDS). The current sensor designs can sample full process flow for line sizes in the range of  $\frac{1}{4}$ " to  $\frac{7}{8}$ " inside diameter. These are the standard line sizes currently implemented in the semiconductor industry for slurry distribution.



Figure 1: The CMP Slurry In-Line Process Monitor

#### Shown in Figure 1:

Process development platform configured with two sets of <sup>3</sup>/<sub>4</sub> flare sensor gangs. One set is for on-line measurements and one set for grab sample analysis. A second set of sensors can be easily reconfigured for on-line measurement of a second independent process stream. All required electronics except for industrial computer are located in the cabinet. The dimensions of the unit are 32"w X 47"h X 21"d.

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The CMP Slurry Monitor measures the following slurry characteristics:

- pH
- Temperature
- Conductivity
- Ultrasonic Attenuation Spectrum
- Particle size distribution
- Dynamic Mobility Spectrum
- Particle zeta potential
- Slurry pressure
- Abrasive particle concentration (weight percent solids).

### 2 System Components

The system block diagram for the CMP Slurry Monitor is shown below, in Figure 2. This section contains a detailed description of the system components shown in the block diagram.





Figure 2: CMP Slurry Monitor System Block Diagram

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(Please refer to Figure 2, the CMP Slurry Monitor system block diagram, for the location of the components described below.)

Industrial Pentium III™ Computer	Acts as the system controller and primary operator interface. All data interfaces between the CD system and the SDS are implemented by the PC. The primary external hardware data interface is an Ethernet TCP/IP network.
Central Signal Processing Unit (CSPU)	This unit consists of radio frequency (RF) analog signal processing electronics for electroacoustic and acoustic property measurements (required for zeta potential, particle size, dynamic mobility, percentage solids, and attenuation spectrum).
	RF signals are transmitted between the CSPU and the remote sensor controller through shielded coaxial cables. If more than one remote sensor controller is deployed, an RF multiplexer is required between the signal processing electronics and multiple remote sensor controllers. The RF signal-processing unit is supplied in a 19" rack-mount cabinet with the industrial PC. The remote sensors can be located up to 30 meters from the CSPU.
Remote Sensor Controller (RSC)	Microprocessor based electronics for remote sensor control and signal processing. Communicates with the PC via an RS 485 interface using a CD proprietary communications protocol. The RSC sources +24V power from the CSPU and provides local control, interfacing and signal processing for the individual flow through sensors. One RSC can service two complete sets of sensors.
	A sensor set consists of the ESA Electroacoustic sensor, % solids sensor, pH sensor, pressure sensor, and conductivity/temperature sensor. The RSC features a back-lit LCD display with soft-key menus for local display of sensor data, calibration of sensors and sensor diagnostics.
Electroacoustic Sensor (ESA Cell)	Flow through sensor for making electroacoustic and acoustic property measurements on the slurry. This data is used to determine the zeta potential, particle size, dynamic mobility spectrum, and attenuation spectrum. One or two ESA cells can be operated with one RSC.
	Each ESA cell requires a corresponding percentage solids, pressure, and conductivity/temperature sensor for conversion of electroacoustic data to zeta potential and particle size.
Abrasive	The % solids cell uses an ultrasonic measurement technique

Concentration Sensor

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(weight percent solids)	to determine the solids concentration (weight %) of the abrasive in the CMP slurry.
pH Sensor	The pH sensor is simply a conventional industrial pH flow cell. All electronics for the pH measurement are located in the RSC. Any commercially available industrial pH electrode may be interfaced to the RSC.
Conductivity & Temperature Sensor	A platinum & glass conductivity electrode integrated with 1K-ohm platinum RTD in a Teflon flow cell. All measurement electronics are located at the RSC.
Pressure Sensor	The pressure sensor is a third party device (strain gauge or capacitive) that is interfaced to the remote sensor electronics.

### 3 Slurry Monitor Output Data

This section describes the output data sets derived from the CMP Slurry Monitor.

#### The Dynamic Mobility Spectrum

The CD CMP Slurry Monitor is based on the company's proprietary electroacoustic technology for measuring the zeta potential and particle size in concentrated colloids.

When an alternating electric field is applied to a suspension of charged colloidal particles, the particles oscillate backwards and forwards in the liquid at the frequency of the electric field. The particle motion in the liquid generates a sound wave known as the *Electrokinetic Sonic Amplitude* or ESA effect. The ESA signal is directly proportional to the particle velocity in the electric field that is called the *dynamic mobility* of the particles.

The dynamic mobility is a fundamental mass transport property of the colloid and can be used to directly monitor CMP slurry reproducibility and quality. Particle size and charge (zeta potential) are determined by measuring how the dynamic mobility of the particles varies with the frequency of the applied field. As the frequency of the electric field is increased, particle inertia (mass or size) causes the particle velocity to become more and more out of phase (lag behind) the electric field.

Also, the magnitude of the particle velocity decreases as the frequency is increased. The dynamic mobility is therefore a complex number; it has both a magnitude and an argument (phase).

The Slurry Monitor measures the dynamic mobility of the colloid over a range of frequencies (1-20 MHz). This data set is known as the *Dynamic Mobility Spectrum* (also known as the *Mobility Spectrum*). A software algorithm is used to fit the measured mobility spectrum to the particle size distribution and zeta potential of the colloid.

The current CMP Monitor measures the mobility spectrum at thirteen different frequencies. Therefore, the mobility spectrum consists of 13 complex numbers or 13 magnitudes + 13 arguments = 26 floating point numbers. SI units are used for the mobility spectrum and typical ranges are:

Mobility magnitudes:  $10^{-10}$  to  $10^{-8}$  m<sup>2</sup> V<sup>-1</sup> s<sup>-1</sup> Mobility arguments: +20 to -50 degrees.

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Particle Size Distribution and Zeta Potential	A software algorithm is used to fit the Mobility Spectrum to the particle size distribution and zeta potential of the colloid. Currently the CD software fits the size distribution to a lognormal distribution function, which can be described by two parameters, the mass median diameter or $D_{50}$ , and the standard deviation of the distribution.
	Normally, two particle diameters, $D_{15}$ and $D_{85}$ represent the standard deviation $D_{15}$ is the diameter where 15% of the particle mass is smaller than this size. $D_{85}$ corresponds to the diameter where 15% of the particle mass is larger than this size. These diameters represent one standard deviation from the median diameter.
	The analysis of the Mobility Spectrum therefore yields the following four scalar floating-point values:
	zeta potential (typical range -150 to +150 mV) $D_{50}$ , $D_{15}$ , $D_{85}$ (typical range for $D_{50}$ 0.07 - 10.0 microns).
Attenuation Spectrum	The ESA sensor used to measure the Mobility Spectrum is also used to measure an acoustic property of the colloid known as the Attenuation Spectrum. When sounds waves travel through a colloidal suspension, some of the sound wave energy is dissipated in the colloid causing the sound wave amplitude to be attenuated.
	There are several mechanisms responsible for this energy loss including:
	• <i>Viscous frictional losses</i> due to relative motion between the particle and the surrounding liquid. This mechanism is driven by a particle-liquid density difference.
	• <i>Scattering of the sound waves</i> by the particles when the particle diameter is comparable to the wavelength of sound.
	• <i>Thermal conduction losses</i> resulting from a temperature gradient between the particle and liquid. This factor is important when the particle and the liquid have different heat capacities and mechanism (a) and (b) above are small.
	• <i>Sound absorption</i> within the solid particle or liquid medium.
	For most CMP slurries used in the IC industry, only the first mechanism is important. The amount of viscous loss depends on the particle size, particle density and the frequency of sound. The CMP Monitor measures the Attenuation Spectrum of the colloid at the same 13 frequencies used for measuring the mobility spectrum and uses this data to determine the average particle

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diameter.

	The Attenuation Spectrum Data therefore consists of 13 floating point numbers reported in units of decibels (dB) per mm. The Typical range is 0.1 to 10 dB/mm.	
	A software algorithm is used to fit the measured attenuation spectrum to the particle size distribution of the slurry. The typical size measurement range determined using the attenuation spectrum method is 0.02 to 10 microns.	
	Similar to the Dynamic Mobility Spectrum, the analysis of the Attenuation Spectrum yields the following three scalar floating-point values: $D_{50}$ , $D_{15}$ , $D_{85}$ .	
Measurement Frequencies	Both the mobility spectrum and attenuation spectrum data sets have a 1:1 correspondence with the measurement frequencies applied in the ESA sensor. The number of measurement frequencies is currently set to 13 over a range of 1-20 MHz. The number of frequencies could change in future versions.	
	The exact measurement frequencies themselves will not change for a given CMP monitor but may vary by application (type of slurry). Mobility spectrum and attenuation spectrum data are usually plotted against frequency in an X-Y scatter plot.	
Abrasive Concentration Sensor (Percent solids)	The percent solids sensor in the CMP Monitor uses an acoustic method to determine the concentration of the CMP abrasive particles. The technique involves propagating a sound wave down a solid rod in contact with the slurry. Some of the sound wave energy is transmitted into the slurry and some of the energy is reflected back down the rod.	
	The CMP Monitor measures the ratio of the reflected sound wave pressure to the incident sound wave pressure. This ratio depends on an acoustic property of the slurry and the rod known as the acoustic impedance. The acoustic impedance of the slurry varies with the abrasive concentration and is used to calculate the solids concentration.	
	The percent solids data is expressed in weight percent. Typical measurement range of the sensor is 2 - 40 wt % with a resolution of 0.1 wt%. Measurement accuracy depends on the type of slurry being monitored. For common abrasive materials used in CMP such as alumna and silica, accuracy is typically +/- 0.15 wt%.	
nH conductivity		

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#### pressure

pH: 1 - 13; resolution .01 pH units conductivity:  $10^{-4}$  to 5 S/m, resolution: 0.1% of reading temperature: 0 - 100 deg C, resolution: 0.01 deg C pressure: 0 - 60 psig, resolution 0.1 psig

## 4 Mechanical Data

The <sup>3</sup>/<sub>4</sub> Flare Sensor Gang layout for the CMP Slurry Monitor is shown below, in Figure 3. This diagram shows the mechanical dimensions of the product.



Figure 3: 3/4 Flare Sensor Gang Layout Dimensions

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Some aspects of the mechanical construction of the CMP Monitor are as follows:

Process Streams and<br/>number of RemoteApreliminaryspecificationdevelopedwithSDSSensor SetsmanufacturersspecifiestworemotesensorsetswillbeGeloyed per SDSrequiring only oneRSC.Different samplepoints in theSDSare switchedthrough the sensors by a valvemanifold.The sensors sample full process flow.

Line sizes and flow rates CD sensors are available to accommodate the following line sizes, flow rates and maximum pressure drop requirements. Sensors are supplied with industry standard Fluoroware type flare inlet and outlet fittings unless otherwise specified.

Line Size (Tube O.D.)	Maximum Flow Rate (L/min)	Maximum Sensor Pressure Drop (PSI)
1/2"	to be determined	to be determined
3/4"	50 Liter/minute	3 PSI
1"	to be determined	to be determined
1 1/4"	to be determined	to be determined

Auxiliary sensor flow streams / sensor calibration The remote sensor sets require provisions for pumping a calibration fluid through the sensors and flushing the sensors with DI water. Calibration must be performed during installation when the sensors are first commissioned. Periodic maintenance/ recalibration schedules have not yet been determined.

Sensor mounting / Sensors should be plumbed in a straight vertical run with fluid flowing up. This minimizes the tendency for air bubbles to be trapped in a sensor and also prevents abrasive particles from settling out on sensor elements during stop flow conditions.

Each sensor set should have a bypass loop in the event a sensor has to be serviced. The bypass loop should be pressure balanced so that the supply pressure does not change significantly when the sensors are bypassed.

Calibration solutions and DI water flushes should be possible while slurry is bypassed.

#### Important

Valve sequencing logic must be designed to ensure that the

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Sensor wetted

materials

sensors are never allowed to run dry with slurry residue in the line. All sensors except for the pH electrode may be left in a dry condition if the sensor loop has been adequately flushed with DI water to remove all residual abrasive material prior to letting the line run dry.

After being stored in a dry state, sensors require a conditioning period with DI water followed by re-calibration with the calibration fluid.

#### ESA Sensor

Flow cell body: Polyphenylene Sulfide (PPS) Tradename is Techtron (DSM Polymers) Seals: Teflon encapsulated Viton or Kalrez Electrodes: Platinum.

#### Percent Solids Sensor

Flow cell body: PPS Seals: No wetted seal materials

#### Conductivity/Temperature Sensor

Flow cell body: Teflon PFA Seals: Teflon encapsulated Viton or Kalrez Conductivity electrode: glass & platinum

#### □ pH Electrode

Flow cell body: Teflon PFA Seals: Teflon encapsulated Viton or Kalrez Electrode: Flat surface glass pH electrode with gel filled reference electrode. Teflon porous junction reference electrode. Electrode body material is PPS

#### Pressure Sensor

Flow cell body: Teflon PFA or PTFE Seals: Chemraz or Kalrez. All other wetted surfaces: Teflon PFA, PTFE or FEP.