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Advanced Process Control and Novel Test Methods for PVD Silicon and Elastomeric Silicone Coatings Utilized on Ion Implant Disks, Heatsinks and Selected Platens

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Abstract - Coatings play multiple key roles in the proper functioning of mature and current ion implanters. Batch and serial implanters require strategic control of elemental and particulate contamination which often includes scrutiny of the silicon surface coatings encountering direct beam contact. Elastomeric Silicone Coatings must accommodate wafer loading and unloading as well as direct backside contact during implant plus must maintain rigid elemental and particulate specifications. The semiconductor industry has had a significant and continuous effort to obtain ultra-pure silicon coatings with sustained process performance and long life. Low particles and reduced elemental levels for silicon coatings are a major requirement for process engineers, OEM manufacturers, and second source suppliers. Relevant data will be presented. Some emphasis and detail will be placed on the structure and characteristics of a relatively new PVD Silicon Coating process that is very dense and homogeneous. Wear rate under typical ion beam test conditions will be discussed. The PVD Silicon Coating that will be presented here is used on disk shields, wafer handling fingers/fences, exclusion zones of heat sinks, beam dumps and other beamline components. Older, legacy implanters can now provide extended process capability using this new generation PVD silicon – even on implanter systems that were shipped long before the advent of silicon coating for contamination control.

Low particles and reduced elemental levels are critical performance criteria for the silicone elastomers used on disk heatsinks and serial implanter platens. Novel evaluation techniques and custom engineered tools are used to investigate the surface interaction characteristics of multiple Elastomeric Silicone Coatings currently in use by the industry – specifically, friction and perpendicular stiction. These parameters are presented as methods to investigate the critical wafer load and unload function. Unique tools and test methods have been developed that deliver accurate and repeatable data, which will be described.

Introduction

Implanter disks, heatsinks and implant wheels are significant contributors to wafer contamination. This contamination includes particles (wafer front and backside) as well as elemental contamination and also cross contamination. Batch ion implanters with disks or wheels represent the vast majority of high current and high energy systems worldwide. Fabs with analog products and also logic products with geometries unaffected by particle damage or those using slower speed disks or wheels continue to use disks and wheels. Many newer batch implant applications are in areas that were not popular in the period when serial high current systems started to become popular for fine geometries (1,2). Some of the newer applications for batch implanters over the last 10 years include wafer exfoliation, higher production volumes with compound semiconductors, MEMS and solar applications. Implant platen disks are typically refurbished every 1-2 years, approximately, depending upon usage – wafer throughput, total dose and species mix. The elastomer coated pedestals are replaced more often depending on the condition of the wafer backside and the throughput. The silicon coating that is replaced today on a disk or other target chamber components such as beam dumps must be of a quality that surpasses the elemental contamination specified in the implanter being refurbished or upgraded when the implanter was originally manufactured. Extended requirements are also needed for the elastomeric coatings on wafer pedestals in terms of elemental purity and for friction and stiction during the usable life of the pedestal and for a variety of substrate types. The reduction of elemental contamination for the majority of IDMs is not only a key driver for implanter OEMs but equally for many suppliers of refurbished beamline and components such as wafer disks/wheels and wafer pedestals especially versions that are seldom supported. In the late 90s to the mid-2000s it became increasingly apparent that devices with ever decreasing smaller geometries suffered increasing device failures due to particle impact effects (1,2). It was reported that implants for < 0.25 µm CD devices start to show the detrimental loss due to ambient particles that strike the wafers due the high wafer velocities (≥ 80m/sec) of a spinning disk (2). In some cases the particle damage is from ballistic effects (particles that are beam-borne). In cases where a fab is operating a disk at slower spin rates than the original, design speeds, there are increased demands on the elastomer product for improved flatness and surface condition as well as other parameters. These criteria/parameters include: charge control, dose uniformity, temperature control as well as wafer handling integrity. There can also be vibration problems early in the speed change exercise due to multiple resonances. Core has seen an increasing % of batch system users requiring reduced disk/wheel speeds. In many cases, these customers often require small but critical changes to elastomer characteristics and extended control of selected manufacturing parameters related to disks or heatsinks.

Table I – Implant Disk/Wheel Features and Affected Process Parameters

Hardware / Component	Criteria / Parameter
Silicon coating integrity/density	Particles (especially in early operation), low elemental contamination and wear
Silicon purity	Elemental contamination (wafer frontside)
Selected disk/wheel components and/or their coatings	Elemental contamination (wafer frontside
Elastomer Purity	Elemental contamination (wafer backside)
Elastomer Surface Quality (Sticktion, Friction)	Wafer handling – transfer, proper seating prior to disk/wheel spin and ease of liftoff after implant
Elastomer coating integrity and wear resistance	Excessive backside particles and, in some configurations, frontside particles and heat transfer

Contamination Control and Performance in Disks and Heat Sinks

The disk factors that contribute the most to the contamination include large areas of implanted areas including various hardware elements that are near the wafer (fingers, fences, charge monitors, etc.) and the elastomer purity. The contamination types include (i) cross contamination from previous species and (ii) elemental contamination from disk surface sputter onto the wafer and (iii) particulates. The latter is especially critical during the initial stage of evaluation. In addition, the elastomer purity and wear characteristics, backside contamination and particles respectively are parameters in need of careful control and an occasional custom tailoring to meet unique substrate backside requirements. It has been reported (4, 6) that >75% of surface contamination comes from a disk

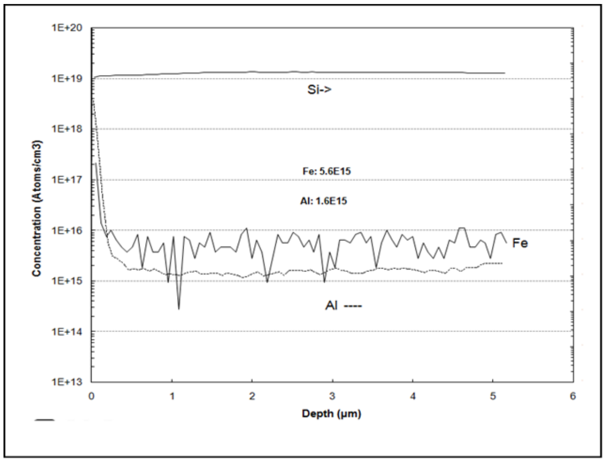
Silicon Coating

Silicon coatings, for the purpose of controlling metallic contamination from beam sputter have come in several forms since the introduction of large area silicon coatings on implant disks starting in 1992 (3). These forms included (i) Silicon flame spray – under a variety of conditions, (ii) PECVD and (iii) PVD. The silicon coating described here, a silicon-dedicated PVD system, is unique in its structure and the elemental purity of wafers implanted on disks with this coating. These various coatings have been used for various applications in beamlines in order to reduce sputter of Al 6061 and its constituents, i.e, Fe, Cr Cu, Ni, Mg, Mn where Mg and Fe are the highest % by weight - after Si of course. These two are each in the range of 0.5-1.2% typically. Silicon coatings became a key option for disks and selected apertures between 1992-1998 (3,5,6).

With silicon coatings, PEVD or PVD as examples, that are done offsite

(local vendor), control has needed to avoid system "memory" where the last process material remains in the system for extended periods – titanium being a common contaminant in this manner. Data from a silicon-dedicated PVD system used for a variety of Silicon applications is used for small to large area silicon coatings are shown in this report. One or more witness sample(s) are checked with Mag Sector SIMS for each PVD coating process setup. Here, in Figure 1 SIMS for Fe and Al – the two most frequently checked species are shown for clarity.

Figure 1 SIMS for Fe, Al in PVD Witness Sample



Here the Fe and Al levels – in the silicon coating are 0.11 and 0.032 ppm of the silicon coating respectively. The other metals that are checked with SIMS are Cr, Cu, Ni, Mg, Mn. None of these were >0.06 ppm. All of these elements are the constituents of 6061-T6 Aluminum (7) –

the common Al alloy used for disk, wheels and heatsinks and associated components.

Silicon Coating Wear

The advanced PVD data shown here is based on a custom PVD system used solely for silicon, Wear tests are done periodically and feedback from users is tracked to ensure that wear equals or exceeds the previous wear experience. The results of a good wear test between standard PVD and PECVD has been previously presented (5) which shows PVD outlasting a PECVD specifically used for disk coating. Figures 2a and 2b show cross sections of the PVD silicon on a "witness sample" presented here.

Fig 2a SEM Cross-section PVD on a Witness Sample

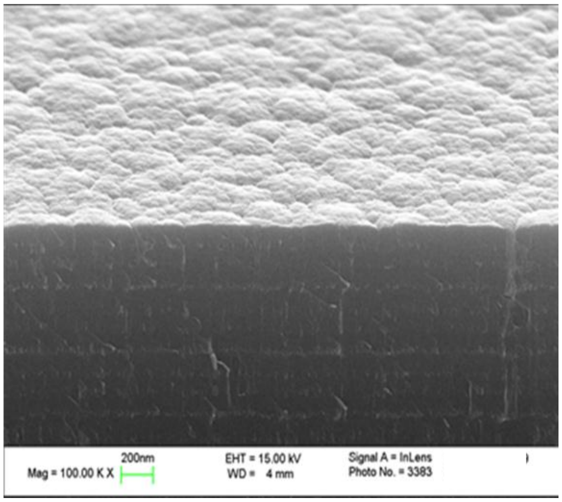
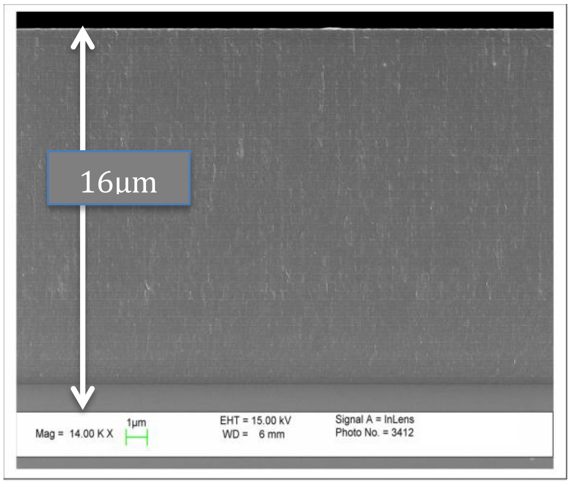


Fig 2b SEM Cross-section PVD



structures. AFM measurements done on prepared disk shields prior to coating show an Ra value of ≤ 15 micro-inches (≤ 0.4 μm) - as an option. The PVD discussed here has a homogeneous, tightly structured formation that does not have the weakness of pronounced grain boundaries with stress points as on other silicon coating methods.

Elastomer Purity

The ultimate purity of the elastomer is highly dependent upon the control and cleaning of the mold equipment and tooling as well as the handling of the completed pedestal. In Table 2, the standard elastomer material was characterized after completion of the molding process using ICPMS. In this test a sample of the elastomer is used and a total bulk analysis is done. The levels shown have become consistent year to year whether on the elastomer material or using a backside wafer test with VPD-ICPMS – test done with wafer frontside down on the elastomer.

Table 2 ICPMS Data – Bulk Elastomer

Element	Concentration (ppm wt.)	Element	Concentration (ppm wt.)
Li	<0.05	Mn	<0.05
B	<0.05	Fe	<0.5
Na	<0.5	Co	<0.05
Mg	0.97	Ni	0.59
Al	12	Cu	0.07
P	0.6	Zn	0.11
Ca	0.7	As	<0.05
Ti	0.12	Zr	6.7
V	<0.05	W	0.12
Cr	<0.05	Pb	0.19

Table 3 VPD-ICPMS of Elastomer to Wafer Transfer After Wafer Upside Down on Elastomer

Elem	PPM	Elem	PPM	Elem	PPM
B	88	Fe	3.8	Sn	4.2
Na	1.05	Co	0.012	Ba	0.25
Mg	0.55	Ni	0.92	Ta	0.0068
Al	10.8	Cu	1.11	W	0.121
Ti	1.9	Zn	3.1	ICPMS Data from Test wafer upside down on pedestal after disk spin	
Cr	1.15	As	2.22		
Mn	0.10	Mo	0.22		

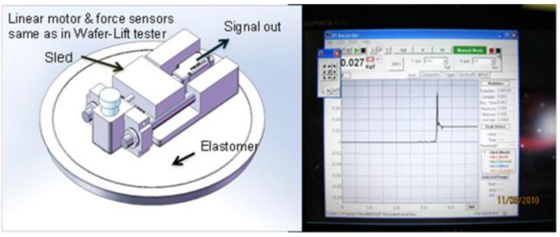
For comparison, in Table 3, the elemental levels on the *front of wafers that were placed upside down on various Core pedestals* at a customer fab are shown. VPD-ICPMS data is shown – the average of two wafers for each element is shown. This shows a good control in the elastomer preparation and molding but also the follow-on work at the fab where there was/is good discipline in disk exposure, handling and installation.

Routine Stiction, Friction and Adhesion Testing of Elastomer

Most implant disk or wheel types are loaded and unloaded when in the vertical position. These disks and wheels – as well as the disks that are loaded horizontally, need to have the wafer moved slightly away from the elastomer prior to proper gripping or robotic handling. The wafer can become “stuck” following a few minutes of implant time due to centrifugal forces creating as much as 120g, after factoring in the “fixed” wafer tilt on the disk (nominal 7º).

The loading of wafers onto disks that are in the horizontal position for load/unload is critical in order to retain the wafer within the confines of the outward fence and the hook site/spring-loaded finger. A low, repeatable (pedestal to pedestal) value of friction and stiction values is required to maintain proper wafer handling and positioning over tens of thousands of wafers before adjustment or maintenance is needed. We refer to the force that is needed to start wafer motion across the elastomer a wafer as “stiction” force (8). In horizontally loaded disk systems, improper elastomer surface characteristics or problems due to backside wafer condition can cause a wafer to hesitate and skip across the elastomer and possibly jump the fence and fall off of the disk. Core has developed two separate instruments – one for Friction and Stiction and one for wafer lift-off force, an “adhesion test” (or perpendicular stiction) in order to ensure that the elastomer surface has the same surface characteristic as that designed for the specific application. Both of these tools are auto-logging. At our facility we reserve the term Stiction solely for the force required to start wafer motion linearly across the elastomer at which point Friction force takes over. Refer to Fig 3 which shows a routine setup for testing the Friction and Stiction – note the classic stiction-friction trace on the laptop.

Fig 3 Stiction/friction Tester



See Table 4 which shows a short series of friction tests on sequential heatsinks. Each elastomer coated pedestal (heat sink) is measured five times.

The Wafer Lift-off force measurement is done using a “Tack meter” or Perpendicular Stiction Force meter designed at Core. The special measurement tip is a piece of silicon wafer of a specific area which is applied in the same manner, each test, on the elastomer surface. This “test piece” can be changed for assessing the substrate adhesion characteristics of other materials that might be on the wafer backside, i.e., Si_3N_4 or other requested materials. Force is applied to a plunger with a “calibrated area”, silicon tip by a stepper motor. The stepper motor that lifts the tip from elastomer and records the force required to do this is measured by a force sensor and transmitted to the hand held computer for read out. See Fig 5 for the data from test sequence of five (5) consecutive heatsinks each tested 5 times. At the present time, the gage sensitivity to force is 0.75-0.8 and.it is also referenced to an internal standard.

Fig 4 Silicon to Elastomer Friction Process Monitor

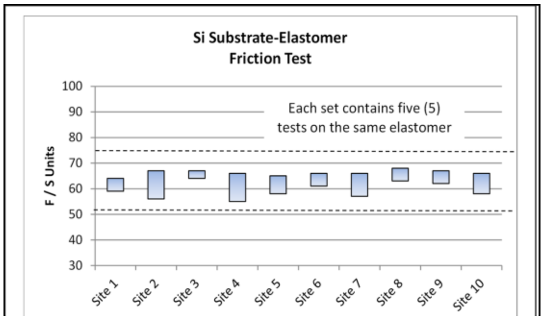
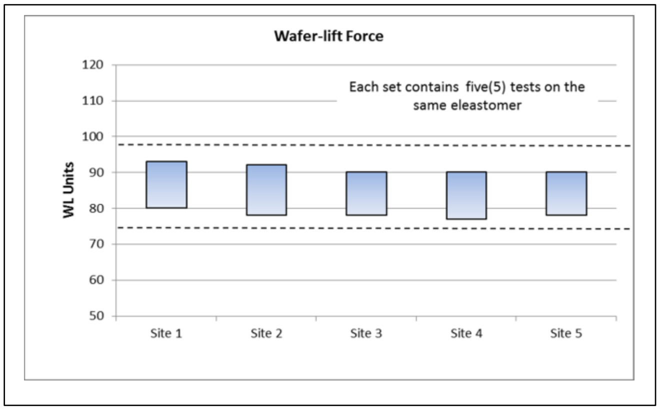


Fig 5 Wafer-Lift Force - Perpendicular Stiction Test



Conclusions

The discipline needed for consistent wafer handling and elemental purity has broadened over the last 10 years due to expanded applications on batch implanters and for extended elemental contamination requirements, The focus now also includes many small niche applications as well as different substrate backside coatings that need to be characterized for proper friction and stiction for proper wafer handling. Silicon coating processes require detailed monitoring of various impurities. The tracking of each production lot and also the control – and dedication of the coating system is critical.

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