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Efficient Cleaning Of Silicon Wafers Using Ultrasonic Technology, Dhiraj K. Sardar, Rugved Nakade, Anthony Sayka, Raylon M. Yow, December 2006

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The surface contamination of wafers, especially by particle contaminants, has been one of the major problems in the semiconductor industry since its inception. The yield on fully processed silicon wafers is inversely related to the defect density of the wafers. One way to decrease defect density is to use efficient cleaning techniques that remove particle contaminants efficiently. Small particles are especially difficult to remove from wafers because of the strong electrostatic forces between the particles and the substrate. It is therefore imperative to find an effective way to remove particles from wafers with efficiency and without damage to the wafers.

Modern wafer manufacturing facilities use stringent contamination control protocols, including the use of clean-room suits, latex gloves, and highly purified ventilation systems. In combination with these protocols, modern manufacturing facilities use various methods of cleaning wafers, often involving pressurized water jet scrubs, rotating wafer scrubbers, wet chemical baths and rinses, and similar systems. These processes, however, are prone to damaging the wafer. In addition, the chemical processes have inherent dangers associated with the use of chemicals, such as sulfuric acid, ammonium hydroxide, and isopropyl alcohol.[1]

Ultrasonic cleaning involves a variety of complex mechanisms, including cavitation, mechanical vibration, etc., depending on whether liquids are used in the cleaning process or not. A typical ultrasonic source is a plane surface that oscillates at a single frequency, producing a longitudinal wave. Vibrational energy transmitted subsequently propagates through the fluid.[2]

In this article, we present an efficient method of cleaning bare silicon wafers with the aid of ultrasonic energy from a low-cost transducer. This work is based on a patent (U.S. Patent # 6,766,813) that describes a method of cleaning a wafer.[1]The method used in this article can be incorporated into a modified vacuum chuck containing an acoustic wave emitter. Additionally, a stream of cleaning liquid can be directed towards the wafer at a shallow incidence angle.[1]However, the present study focuses only on the use of acoustic energy to clean a wafer.

SEMICONDUCTOR WAFER

The semiconductor industry uses various types and sizes of wafers. Depending on the type of process technology, wafer sizes can range from 100–300 mm, and both p-type and n-type wafers are common in the industry. In this investigation, experiments were performed using a 100-mm diameter, p-type silicon wafer with a thickness of 540 µm.

CONTAMINANT PARTICLES

Various types and sizes of particles can contaminate semiconductor wafers during the fabrication process. Silicon and silicon dioxide are two commonly found contaminants on semiconductor wafers and, hence, were used in our experiments. Also, it should be noted that particles of nanometer size can reduce the yield of smaller geometry circuits and are to be avoided and removed from wafers if possible. Particles of such small size were not attainable for this study. However, silicon and silicon dioxide particles at the micrometer level were obtained using a U.S. Customary sieve shaker (Gilson Company Inc. SS-12R) and crushed silicon and silicon dioxide. Silicon particle sizes obtained for use in this experiment were: 53–90 µm, 90–125 µm, and 125–300 µm. Silicon dioxide particle sizes obtained for use in this experiment were: 38–45 µm, 45–53 µm, and 90–150 µm.

MODELLING

We consider symmetric radial vibrations of a thin circular plate with free support. The symmetric longitudinal natural frequencies were calculated from the following equation:[3]

$$\text{Eq. 1} \quad f_m = \frac{\beta_m}{2\pi R}\sqrt{\frac{E}{(1-\nu^2)\rho}}$$

where R is the radius, E is the modulus of elasticity, is Poisson's ratio, and is the mass density. The values of m are determined from the roots of the solution of the equations of motion for free vibrations with free support:[3]

$$\text{Eq. 2} \quad \beta J_0(\beta) - (1-\nu)\, J_1(\beta) = 0$$

where J_0 and J_1 are Bessel functions of the first kind. In calculating resonant frequencies, we used the following values: R = 5.0 cm, E = 10.7 x 10^{12}dyn cm^{-2}, = 2.330 g cm^{-3}, and = 0.22.[4,5] The first two solutions for equation 2 $\beta_1 = 1.998$ and $\beta_2 = 5.374$. Employing these in equation 1, we calculate the first two natural frequencies as $f_1 = 44.2$ kHz and $f_2 = 118.8$ kHz. Note that the first natural frequency differs from the ultrasonic transducer frequency used in this study by only about 6 kHz.

EXPERIMENT

An ultrasonic cleaner (RadioShack 63-116) was purchased from a local supplier. The ultrasonic cleaner is housed in a plastic casting designed to be held in hand by a user to clean various materials. The reason for using this transducer was its low cost and that the frequency of the transducer, measured to be 50 kHz with an oscilloscope (Tektronix 2445A), is close to the natural frequency (44.2 kHz) of the first axial symmetric longitudinal vibrational mode as discussed above.

Figure 1. Ultrasonic tranducer

Figure 2. Nikon SMZ-U microscope

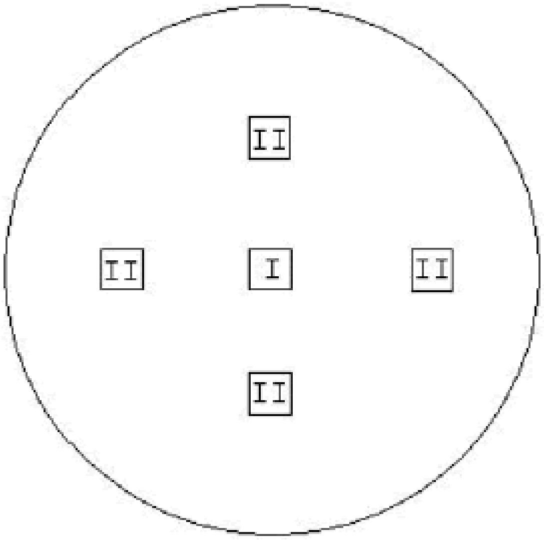


Figure 3. Sites studied on a 100-mm diameter wafer

Standard cleaning procedures of the semiconductor industry take place in cleanrooms. However, a cleanroom was unavailable for this study. During the experiment, the wafer was placed on foam to simulate free support boundary conditions. The wafer was supported by the foam only at the perimeter of the wafer such that only about 2 mm of the edge of the wafer was in contact with the foam. The ultrasonic cleaner transducer unit was mounted on an optical stand and positioned such that the transducer was in contact with the center of the back of the wafer as shown in Figure 1. An optical stereoscopic microscope (Nikon SMZ-U) equipped with a 5-million pixel Color Matrix CCD (Figure 2) was used to obtain high-resolution micrographs of particulates on the wafer surface both before and after application of the ultrasonic transducer. Micrographs are taken with the CCD camera attached to the microscope and processed by a personal computer equipped with optical processing software.

A 100-mm diameter, p-type silicon wafer of thickness 540 microns was used for all experiments. Five sites, each having an area of 1 cm2, were etched on the wafer surface for data collection as shown in Figure 3. The par-ticulates counted on these squares form the representative sample of the data. One square represented as I is placed at the center of the wafer. The other four squares represented as II are radially located at a distance of 2.5 cm from the center of the wafer.

The wafer was thorougly cleaned before each experiment with methanol to ensure that no particles from a previous experiment remained on the wafer. Particles of a specific size were sprinkled on the front surface of the wafer. The wafer was turned face down and tapped lightly on the back to remove loose particles that did not stick to the surface of the wafer. The wafer was then placed under the microscope and particles were counted from the Nikon micrograph captured on the computer monitor. The wafer was again placed with its front side down such that the outer rim of the wafer would be freely supported by foam to allow any dislodged particles to fall due to gravity directly below the wafer. In order for the particles to be dislodged from the wafer surface, the ultrasonic transducer was placed at the center of the back of the wafer and kept in contact for 60 seconds. Particles dislodged from the wafer due to the ultrasonic vibrations were collected on a piece of white paper placed directly beneath the wafer front face and enclosed by the walls of the foam. The wafer was then placed under view of the microscope for another count of the particles. Mi-crographs of the wafer surface before and after application of the ultrasonic transducer were captured using the CCD camera attached to the microscope, a computer, and associated software. Typical micrographs of the wafer surface before and after application of the transducer are shown in Figures 4 and 5, respectively.

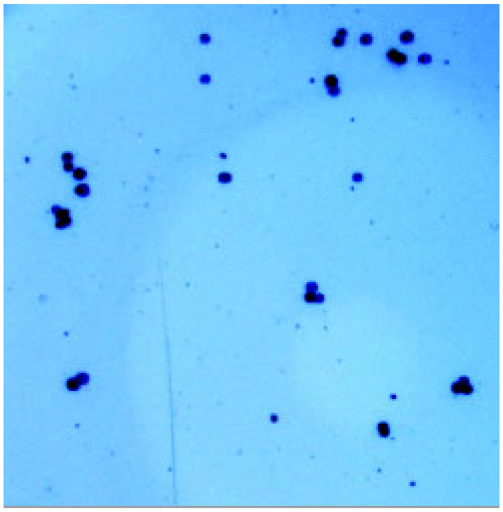


Figure 4.
Silicon dioxide particles on wafer before excitation

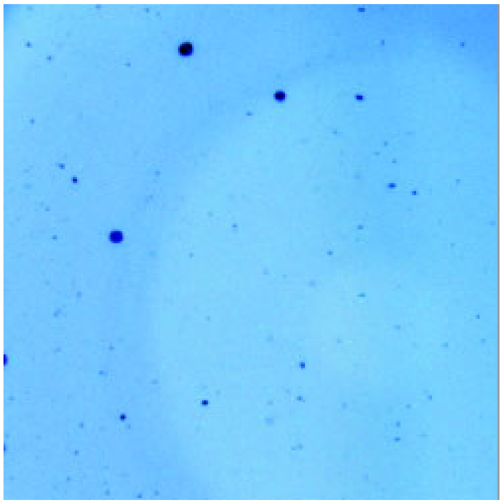
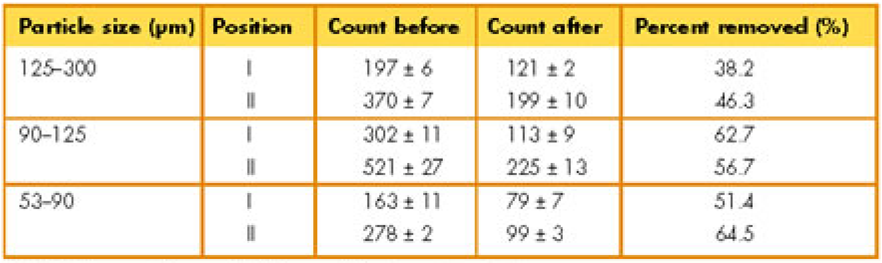


Figure 5. Silicon dioxide particles on wafer after excitation

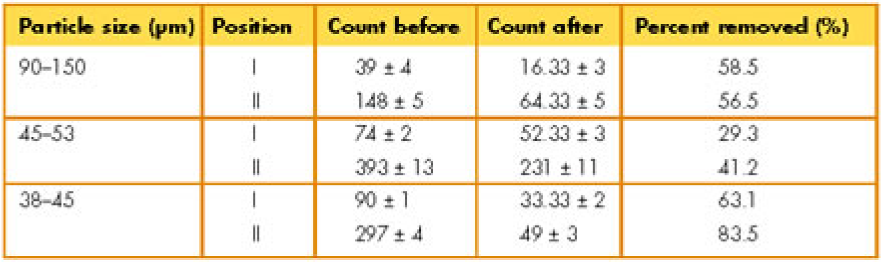
RESULTS AND DISCUSSION

Since the typical particle contaminants of semiconductor wafers found in the fabrication process are usually silicon and silicon dioxide, these two types of particulates were used in this study. Particles of these two materials having diameters between 38–300 µm were placed on a p-type semiconductor wafer. The efficacy of the 50-kHz ultrasonic transducer to remove these particles was studied with regard to particle type, particle size, and particle position on the wafer. Particles were counted three times for each experiment. The average particle counts and standard deviation of these values are reported in Tables 1 and 2 for silicon and silicon dioxide, respectively.



Particle size (µm)	Position	Count before	Count after	Percent removed (%)
125–300	I	197 ± 6	121 ± 2	38.2
	II	370 ± 7	199 ± 10	46.3
90–125	I	302 ± 11	113 ± 9	62.7
	II	521 ± 27	225 ± 13	56.7
53–90	I	163 ± 11	79 ± 7	51.4
	II	278 ± 2	99 ± 3	64.5

Table 1. Silicon particles on wafer before and after ultrasonic application.

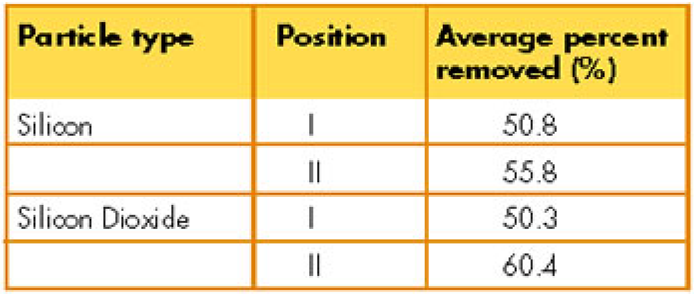


Particle size (µm)	Position	Count before	Count after	Percent removed (%)
90–150	I	39 ± 4	16.33 ± 3	58.5
	II	148 ± 5	64.33 ± 5	56.5
45–53	I	74 ± 2	52.33 ± 3	29.3
	II	393 ± 13	231 ± 11	41.2
38–45	I	90 ± 1	33.33 ± 2	63.1
	II	297 ± 4	49 ± 3	83.5

Table 2. Silicon dioxide particles on wafer before and after ultrasonic application.

Position I represents the number of particles counted on the square etched at the center of the wafer. Position II represents the sum of the number of particles found on the four squares etched at a radial distance of 2.5 cm from the center of the wafer (see Figure 3). Data presented in Table 1 indicates that overall, a greater percentage of silicon particles are removed from Position II (radial distance) than from Position I (center). A similar result is observed also for the silicon dioxide data provided in Table 2. Regarding particle size, Table 1 shows the largest silicon particles, 125–300 µm, were least effected, while Table 2 shows that the middle-sized particles for silicon dioxide, 45–53 µm, were least effected. Hence, we conclude that the number of particles dislodged are not strongly dependent on the size of the particles. Table 3 shows an average of percentage of particles removed from all particle sizes at Positions I and II for both silicon and silicon dioxide. From these averages, it is apparent that at Position I, the percentage dislodged for silicon and silicon dioxide are almost the same; for Position II, the percentage dislodged differs by only about 5%.

In the semiconductor industry, the size and type of contaminants determine the cleaning techniques used. In this experiment, it is observed that the use of ultrasonic energy dislodges particles regardless of the size or type. Apparently, there does not seem to be a strong dependence between those characteristics and the ultrasonic cleaning process. It can therefore be concluded that the method used in this study to clean a wafer is effective for removing both silicon and silicon dioxide particles above roughly 38 µm in diameter.



Particle type	Position	Average percent removed (%)
Silicon	I	50.8
	II	55.8
Silicon Dioxide	I	50.3
	II	60.4

CONCLUSION

A novel and efficient technique for cleaning silicon wafers using acoustic energy in the ultrasonic frequency range has been presented. This novel method has demonstrated that particles of a wide range of sizes can be removed efficiently from the surface of bare silicon wafers with ultrasonic energy. It is expected that the cleaning process discussed in this article can be applied to patterned wafers of a variety of sizes as well. Naturally, in a manufacturing environment, a vacuum chuck-based ultrasonic transducer (as specified in the patent) would take the place of the free foam set up.

Although a single frequency of 50 kHz has been employed to remove particles from non patterned wafers, we would like to extend this work to cover all aspects of the patent, that is, application of high pressure liquids, multiple frequencies, and wafer rotation, to clean particles from both bare and patterned wafers. A future, extended study will lead to the development of a prototype of the aforementioned patent.

Acknowledgment

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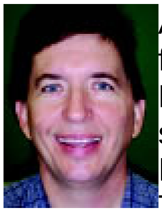

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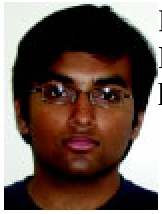

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