Direct Wafer Polishing with 5 nm Diamond

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ABSTRACT

CMP for making future semiconductor chips with nanom (nano meter) feature sizes can be accomplished by using nanom diamond particles embedded in an organic matrix (e.g. epoxy). Such nanom diamond particles are derived from the detonation of dynamite (e.g. TNR and RDX) in oxygen deficiency atmosphere. The nanom diamond particles are formed instantaneous from the residue carbon during the transient ultrahigh pressure and temperature. These nanom diamond particles are defect ridden and they are coated with a softer carbon coating (e.g. bucky balls and nano tubes). The softer carbon coating can lubricate the cutting edge in-situ during the action of nanom polishing. The nanom diamond has an intrinsic tight size distribution (4-10 nanoms) so the scratch of delicate semiconductor chip (e.g. IC with copper circuitry) is avoided. Moreover, the nanom diamond itself contains built-in defects that will allow nanom chipping so the abrasive can be self-sharpened for continual polishing with high efficiency. In addition, the nano radius of the nanom diamond can polish the wafer in the ductile domain so chipping of the polished surface is avoided. The result would be a clean and smooth surface with minimal mechanical degradation or thermal damage. The resinoid matrix that holds nanom diamond is impregnated with nanom metal particles (e.g. Ni) that can be dissolved by acidic slurry. Alternatively, the epoxy matrix may also incorporate nanom salt particles (e.g. NaCl) that can be dissolved in water. The dissolution of non-carbon nanom additives will expose new nanom diamond particles continually so the efficient polishing can be sustained.

Keywords: nanom diamond, CMP, ULSI, wafer polishing, moore's law

1 NANOM DIAMOND POLISHING

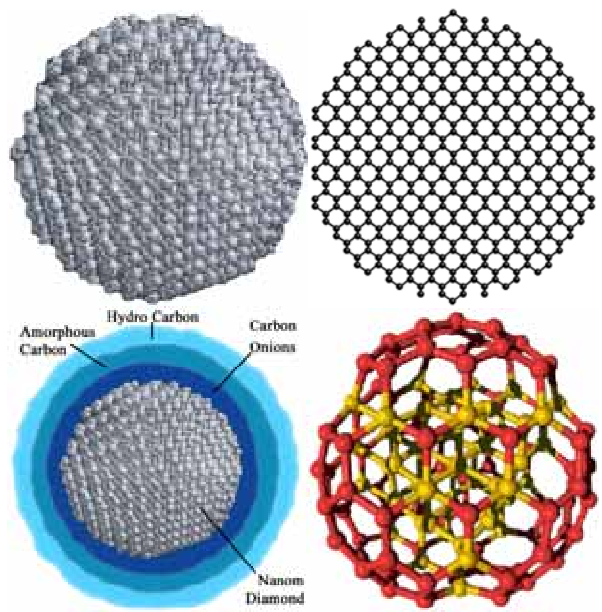

Figure 1: Dynamite derived nanom diamond particles contains high concentration of defects (top left) that can allow gradually nanom chipping during polishing. The particle is about 5 nm across in size with about 30,000 carbon atoms (top right). The nanom diamond particle is coated with non-diamond carbon soot that may serve as a damper for reducing the impact force (bottom left). The carbon soot may also form bucky ball that encloses the nanom diamond particle (bottom right).

Nanom diamond is small and spherical with tight size range, so it is ideal for achieving super smooth polishing. Because it is superhard, it can penetrate effectively into the wafer surface and chip off the protruded points. Hence, the polishing rate would be an order of magnitude higher.

Moreover, as diamond is much harder than the wafer material, it can penetrate into the work material with the least energy so the surface damage due to plastic deformation or thermal degradation would be minimal. In other words, the polished surface would be clean and smooth with little or no dragging or smearing.

In is well known that during the cutting process, the damage of work material is inversely related to the sharpness of the cutting edge. Hence, cutters with smaller radii can make cleaner cutting surface. Consequently, nanom diamond particles will not drag on the wafer surface during polishing so the wafer surface would be smoother.

In addition, the nanom diamond particles are so small that only a few layers of atoms will be removed from the wafer each time. Such a nanomatic cutting operation will render the wafer ductile. In other words, the wafer surface is shredded off rather than chipped off. The nanom peeling of wafer material can generate the least heat so it is also a cold polishing process. In contrast, the larger particles will cause much mechanical damages to the wafer surface due to plastic deformation and brittle chipping. If the hardness of the abrasive is not superhard, as in the case of using ceramic fines, both the wafer surface and the abrasives will smear and fracture. As a result, significant heat is produced at the contact area that may rise the temperature momentarily. The transient hot spot may not only leave behind a thermal damage zone on the wafer surface, but also could soften or even melt the polyurethane matrix. Such a thermal shock is not acceptable when the wire width is narrowed down to 90 nm or less.

In contrast, the cold polishing of nanom diamond produce no trace of thermal damage. Moreover, the ductile polishing can make the surface super smooth like a shinning mirror. This is the ultimate CMP process for making all transistors identical with perfect flat circuitry, i.e., absolutely no dishing. Hence, nanom diamond CMP process can be the enabling technology for advancing Moore's Law to make transistors with feature sizes smaller than 65 nm.

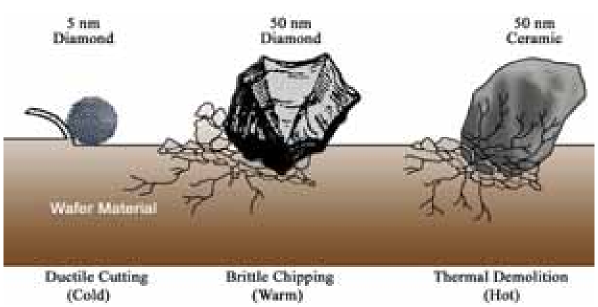

Figure 2: Nanom diamond particles are superhard and super sharp so they can remove only a few atomic layers of the wafer materials. As a result of this restricted penetration, the polishing is achieved by ductile peeling of the normally brittle material. Such a cutting mode will damage the least the fragile low K dielectric on the wafer. Consequently, the finished surface is both ultra precise and supersmooth. In contrast, the irregular shaped and over sized diamond superabrasive or ceramic abrasives cannot polish the wafer in the ductile domain. The forced penetration of these large particles will cause brittle chipping of the low K dielectric, in the case of superhard diamond, or thermal degradation, in the case of ceramic abrasives.

2 DIRECT POLISHING OF WAFER BY NANOM DIAMOND

As nanom diamond is much harder than conventional ceramic abrasives (e.g. silica, ceria, alumina, silicon carbide) used for CMP, it can penetrate deeper into the work material so the polishing rate would be higher. Moreover, as the plastic deformation or thermal damage is less on the polished surface, the smoothness of the wafer surface is greatly improved.

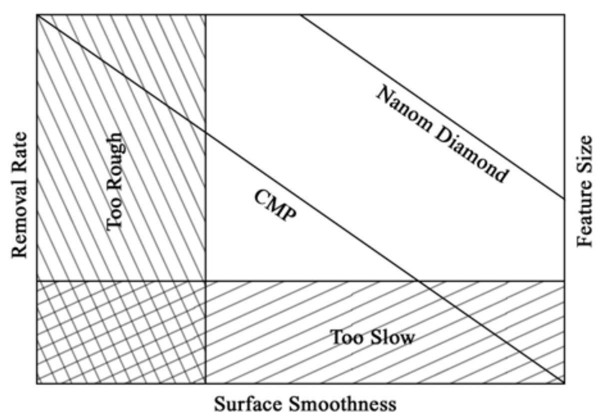

Figure 3: The polishing rate of conventional ceramic abrasive for CMP is compromised by the super smooth finish required for making future chips. The polishing rate of superhard nanom diamond is significantly faster and the polishing action is much less damaging, so nanom diamond polishing can produce super smooth wafer surface without sacrificing much of the productivity.

Although nanom diamond may be ideal for polishing wafers, it is too expensive to be mixed with slurry. The abrasive particles in slurry can move around freely so most of them are not used in polishing, but they are lost with the flow of the slurry. In order to minimize the loss of expensive nanom diamond, the particles must be impregnated in a solid carrying medium (bonding matrix), such as resin or polyurethane.

Because nanom diamond particles are exceedingly small, their exposure above the bonding matrix for effective cutting is minimal. Consequently, dragging of wafer against the bonding matrix is inevitable. Moreover, the polished debris cannot be removed around nanom diamond particles. The over coated polishing matrix must be removed by an effective dressing action. It is preferable that the amount of dressing is controllable as nanom diamond particles may be lost by excessive exposure.

3 NANOM DIAMOND POLISHING PAD

Because nanom diamond is relatively expensive (e.g. $1/carat or $5/g) and it is about 100 times more costly than conventional nanom abrasives, it is not suitable to be used as free slurry. Consequently, the nanom particles must be embedded in a fixed matrix. The use of fixed matrix will not only preserve the nanom diamond, but also allow it to cut more aggressively into the wafer surface. Consequently, the polishing rate would be further increased.

Nanom diamond particles have a tremendous amount of surface area (e.g. 300 m^2/g), so it can be attached firm in a suitable resin matrix (e.g. epoxy). This is further enhanced by the non-diamond carbon coating that is wettable by most organic materials such as resin or epoxy. The wetting will increase the adherence strength significantly due to the formation of chemical bonds between carbon and matrix atoms.

The nanom diamond impregnated matrix can be selectively coated on a pad surface such as that by forming "poles" that protrude above the surface. These poles can exert pressure on the wafer to be polished. A convenient method to stick poles on the pad is by screen-printing. In this case, nanom diamond particles are first dispersed (e.g. in an emulsifier in a liquid (e.g. acetone) and mixed in with a binder mixture (e.g. amino resins, phenolic resin, epoxy resin, arcrylated polyester resin, or others) to form a suitable paste with the right viscosity. The paste is then printed on a proper pad material (e.g. myler, PET) through a screen (e.g. reinforced laminate board) that contains patterned holes with the size and distribution that are intended for making poles. After the printing, the precursor materials of poles can be cured by evaporation of solvent under an infrared lamp, by ultraviolet polymeration or cross-linking of monomers or oligomers.

The poles do not have to be formed on a polishing pad; it may also be coated on a flat wheel or a cup wheel. In this case, the nanom CMP is accomplished by fast rotation of the wheels against the wafer. The operation is similar to grinding, but the polishing action is orders slower in material removal, and significantly lower in contact pressure.

The poles carrying pad must be properly supported by subpad materials in order to achieve local planarization and global uniformity. Certain designs have been used to achieve the optimal compromise of the two planarization scales. Thus, U. S. Patent 6,632,129 described the use of an intermediate layer of segmented tiles between fixed abrasive pad and a resilient subpad to allow local adjustment of planarization over the global scale. In this case, the rigid tiles (e.g. Young's modulus > 200 MPa) can tilt locally as a whole over an elastic support material (e.g. Young's modulus <100 MPa). All layers can be conveniently glued by pressure sensitive adhesive such as latex crepe, rosin, acrylic polymers and copolymers, alkyd adhesives, rubber adhesives.

Suitable rigid material may be made of polycarbonates, polyesters, polyurethanes, polyolefins, polyperfluoroolefins, polyvinyl chlorides, and other thermo-plastic materials. Alternatively, thermosetting copolymers may be used, such as epoxies, polyimides, polyesters, and copolymers with at least two different monomers (e.g. terpolymers, tetrapolymers).

In contrast to the above patent teaching, it is desirable to support the poled pad with either more than one layer of segmented tiles or more than one size of segmented tiles in order to smooth further out the stress that may be built on the interface between poled pad and tiles, and between tiles and subpad. In this case, the local planarization can be uniformly cushioned by the resilient subpad so the polished wafer will not see abrupt changes of local planarization markings.

4 SELF-SHARPENING NANOM DIAMOND PAD

In order to expose the nanom diamond particles that are embedded in the matrix, the matrix may be selectively dissolved in an organic solvent. The solubility of the matrix in the solvent is higher when the pressure is increased. As a result, the matrix around each nanom diamond particle that is pressing against the wafer will be etched away preferentially. The exposed nanom diamond particle can then cut into the wafer more effectively.

Alternatively, the matrix that holds nanom diamond particles may also be added with another ingredient that can be dissolved uniquely by another solvent. For example, the matrix may contain nanom nickel particles that may be dissolved by nitric acid diluted in water. The preferential dissolution of nickel particles around nanom diamond particles may expose the latter for fast polishing action.

In summary, by incorporating nanom diamond in fixed matrix can allow fast polishing of future wafers without causing scratching of super smooth surface. Because nanom diamond is superhard with much higher wear life, and the fact that fixed abrasive is significantly less waste that free moving slurry, the work life of nanom diamond may be a thousand times more than that of conventional abrasive. This long life will make the nanom diamond more economical because it is only about 100 times more expensive in price. In addition to cost less, nanom diamond cannot scratch the wafer so the production yield of the polished wafer is higher. Moreover, nanom diamond can polish with minimal energy so the surface damage of the wafer is avoided. Furthermore, nanom diamond can polish in the ductile domain. As a result, the wafer surface will be super smooth. Thus, the direct polishing of wafers by nanom diamond has the potential to make future chips required by Moore's Law in cost, quality, and throughput.

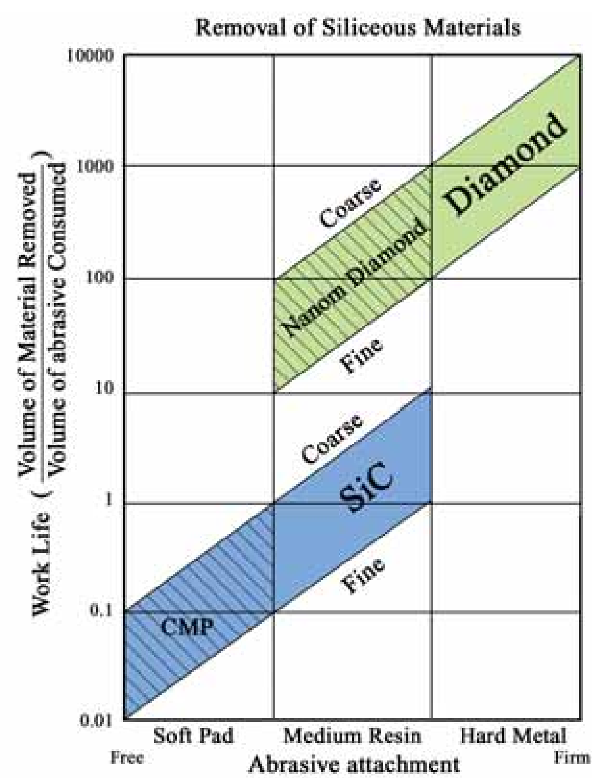

Figure 4: The polishing life of nanom diamond versus conventional abrasive labeled as CMP. The figure shows that the firm attachment of superhard nanom diamond can last about 1000 times longer than free moving ceramic abrasive particles.

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