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# THE USES OF MAN-MADE* DIAMOND IN WAFERING APPLICATIONS

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The continuing, rapid growth of the semi-conductor industry is requiring the involvement of several specialized industries in the development of special products geared toward the unique requirements of this new industry. The Specialty Materials Department of General Electric has often accepted the challenge of developing a specialized manufactured diamond to meet various material removal needs. The area of silicon wafer slicing has presented yet another challenge -- and it is being met most effectively. Before discussing how MAN-MADE diamond can be useful in slicing wafers, a look at the history, operation, and performance of MAN-MADE diamond is in order.

## The History of MAN-MADE Diamond

Natural diamond was first found in India. Later, much larger deposits were found in South Africa and other countries on the African continent, like the modern Zaire, Ghana, and Sierra Leone. In more recent times, the Soviet Union has emerged as a major supplier of mined diamond, and very recent discoveries in western Australia show considerable promise.

In 1951, a project was started by scientists at General Electric who recognized that industry would need more stable reliable sources for diamond. Diamond, as the scientist knew, was a form of carbon, the same material that composes graphite. The GE researchers felt they could create diamond by compressing and then heating the graphite structure. They knew they would have to design equipment that would exert tremendous forces of heat and pressure great enough to change the atomic structure. The change would have to be powerful enough to form the characteristic three dimensional covalent bond that gives diamond its unmatched hardness.

They developed apparatus capable of producing and containing very high pressures and temperatures that could be controlled for adequate time periods and could be reproduced.

But innovative apparatus was only part of the solution. It was discovered that a catalyst was also necessary for the transformation to take place. With this discovery, all the pieces fell into place. In 1955, General Electric announced that they had, in fact, manufactured real, non-artificial diamond in the laboratory. It passed all the tests. It scratched natural diamond, it would not dissolve in acid, oxidized at high

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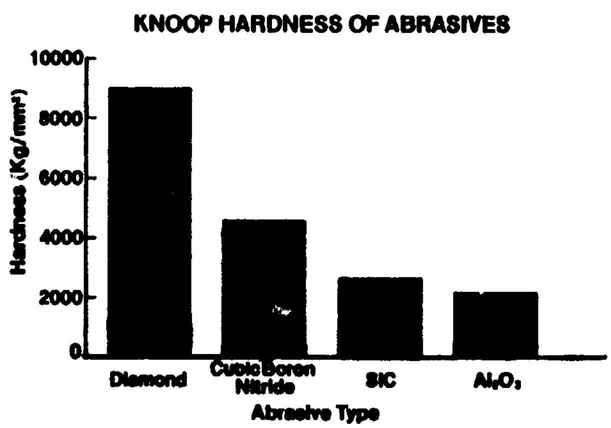
temperatures as mined diamond does, and passed x-ray diffraction patterns identical to natural diamond. GE went on to make other important contributions and discoveries about the nature and formation of diamond. For example, they discovered that the catalyst could be any one of a variety of metals, the carbon used as a starting material affected the character of the diamond formed, and temperature differences could produce diamond crystal color varying from black when manufactured at low temperatures through dark green, light green, yellow and white at the highest temperatures. Color is also affected by the presence of non-carbon atoms in the diamond crystal.

General Electric has even demonstrated the ability to synthesize a variety of gem size and gem quality stones.

For a wide number of reasons that will be discussed later, manufactured diamond has been rapidly growing in popularity ever since its introduction in 1957. It is now used almost five times more often than mined diamond in industrial applications and still growing steadily.

Why Use MAN-MADE* Diamond?

MAN-MADE diamond has properties such as hardness, abrasion resistance, compressive strength and thermal conductivity that make it a logical choice over conventional abrasives for many applications.




(Fig. 1)

The Knoop hardness test (Fig. 1) is a standard method for measuring the hardness of exceptionally hard and brittle materials and individual grains and particles. It is an indentation test. and thus, is regarded as a true test of the relative hardness of materials. It can readily be seen here that diamond far surpasses the conventional abrasives in hardness.

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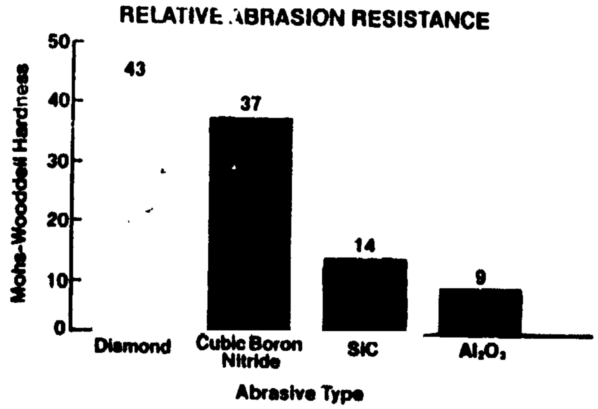
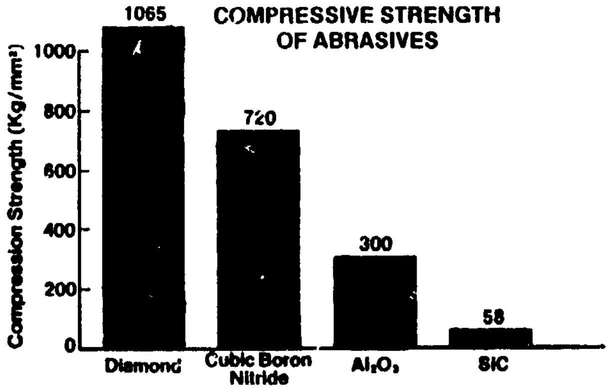
(Fig. 2)




The relative abrasion resistance (Fig. 2) calls for some explanation. Note that the vertical scale on the chart is labelled "Mohs-Woodell Hardness". However, the Mohs-Woodell hardness determination is the result of "rubbing" materials together; thus the values obtained are essentially measures of relative abrasion resistance instead of hardness. The important point, of course, is that diamond is significantly more abrasion resistant than either aluminum oxide or silicon carbide.

(Fig. 3)




The high compressive strength value (Fig. 3) of diamond is expected in light of the atomic structure of diamond. Essentially each crystal is composed of carbon atoms arranged in face-centered lattices forming interlocking tetrahedrons and also hexagonal rings in each cleavage plane. Each carbon atom in the crystal is surrounded by four other carbon atoms lying at the corners of a tetrahedron. These four atoms are connected by covalent bonds to the original carbon atom. In turn, each of the four corner atoms is connected to four other carbon atoms, including the original, by covalent bonds. This pattern persists throughout the entire diamond crystal so that each crystal is one giant molecule, accounting for its hardness. Therefore, in order to break the diamond crystal, many covalent bonds must be broken. This requires a large amount of energy.

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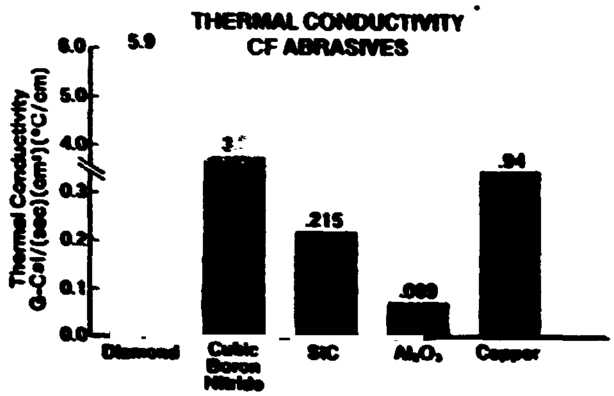
(Fig. 4)




The high thermal conductivity of diamond (Fig. 4) is an advantage for material removal applications. Heat generated during the operation is rapidly dissipated through the superabrasive material into the grinding wheel or tool thus reducing the risk of thermally damaging the workpiece material. A characteristic of great importance when slicing silicon wafers.

How Does MAN-MADE* Diamond Work?

When using a tool impregnated with MAN-MADE diamond, each abrasive particle on the periphery of the tool contacts the workpiece, acting as an individual cutting tool and removing a minute chip, or particle, from the surface of the material being ground. In addition to its hardness characteristic, it is important that a diamond have good sharp cutting edges with which to remove material. In time, these cutting edges could be worn smooth making the diamond less effective unless the proper kind of diamond is utilized. This is where a MAN-MADE diamond, tailored to a specific application becomes so beneficial. One of the benefits of MAN-MADE diamonds in this type of application is that they are designed to micro-fracture. That is, before their cutting edges become too worn they actually break away exposing new, sharper cutting surfaces to maintain the good free-cutting characteristics of the tool.

A combination of these MAN-MADE diamond characteristics and the process by which material removal is accomplished leads to a cutting tool with excellent performance. This shows itself by a longer tool life experienced over conventional abrasives, a higher stock removal capability, the ability to hold and maintain much tighter tolerances on the workpiece, and a much higher degree of productivity.

One final characteristic that sets MAN-MADE diamond apart from mined diamond and other abrasives are the strict set of quality control procedures that each shipment of diamond must pass before being delivered. Over 15 product tests are conducted on each shipment of GE diamond before leaving our plant. Some of the key tests that GE demands to maintain a consistently high quality diamond are ...es used to measure a diamond's toughness, bulk density, size, and appearance. The first is the test of toughness.

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The term friability is used to refer to an impact strength measurement which is conducted on diamond products. At GE, we refer to this parameter as our products' Toughness Index. This refers to a test which measures the resistance to impact fracture of the crystal when it is subjected to a controlled duration of destructive ball milling.

Bulk density testing is a test which is an ANSI standard in the United States. Of the two tests in common use, GE uses ANSI B-74.4, because of the greater degree of accuracy it yields due to the use of very large test samples.

Size testing is based on the existing ANSI and FEPA standards for the size of diamond grains. It is interesting to note that both of these standards were developed on the basis of work done at the Specialty Materials Department of GE. Only costly, precision electroformed screens are used in this test.

In addition to a wide number of other tests, a visual examination is given to each batch of diamond to be sure that crystal size, shape, color, and other physical characteristics are consistent with all other shipments of that product.

As you can now well understand, a MAN-MADE* diamond which can be grown, sized, and tested to meet a specific application need is the very type of product needed in a field of such growing sophistication as the semiconductor industry. Furthermore, in light of the recent natural diamond shortage and with the prospect of continued disruptions in the supply of mined diamond, it appears as if the goals of that original GE research team in providing a more stable and reliable source of diamond are becoming even more critical to industry today.

How Is MAN-MADE Diamond Being Used?

A brief look at some of GE's existing MAN-MADE diamond product families will illustrate how they have been tailored for specific applications.

RVG - The earliest GE product offering, is composed of very friable, irregular crystals most frequently used with a nickel or copper coating which totally covers the entire exterior surface. This diamond is designed for use in resin or vitreous bonds and used when processing cemented tungsten carbide, carbide-steel combinations, cermets, and diamond or cubic boron nitride compacts tools.

MBG - A medium tough to tough regular crystal which ranges in color from yellow-green to light yellow and almost white. This product is aimed for use in metal and plated bond applications and is used for processing glass, ceramics, ferrites, plastics, fiberglass and other materials.

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MBS - This product is composed of tough, blocky cubo-octaheydral crystals with predominantly smooth faces. Generally the crystals are transparent or translucent and range in color from light yellow to medium yellow-green. Designed for metal bond applications and used in processing stone, concrete, refractories and other highly abrasive materials.

Micron Powders - A product made up of blocky crystals generally less than 60 microns in size. It is available in either a diamond graded or ungraded form or BORAZON* CBN. Micron Powders are used as a loose abrasive or for lapping and polishing in slurries or compounds and has been tailored for use in processing dies, ceramics, stone, metallurgical specimens, gemstones and other metals, and more recently has been successfully used in silicon dicing blades.

BORAZON CBN - (Cubic boron nitride) - These crystals vary from sharp, irregular shape to strong, blocky shape with the color varying from black through translucent orange-brown. BORAZON CBN was developed in 1956 by General Electric specifically for the processing of steel, cast irons, ferrous nickel, cobalt base alloys, and stainless steel.

Within each of these major product groups, separate product offerings have been developed for even more specialized applications making the total number of GE diamond product types well over 200, with many more to follow.

Some of these products are currently being used as a silicon wafer slicing diamond while development work is being done on MAN-MADE diamond specifically tailored for this application. But, before turning our attention to silicon wafer slicing with MAN-MADE diamond, let us first examine the types of requirements that would be made on such a product.

## The Slicing of Silicon Wafers

Silicon Wafer Slicing makes some very specific demands upon the slicing saw that should be addressed before considering the type of blade to use.

A major problem encountered with blades is the excessive heat generated at the point of cut. This heat build-up results in a degradation of the quality of the cut due to the possible disintegration of the abrasive material used.

Of the major sources of heat build-up, coolant starvation is the most common. The rotating blade acts as an air pump creating a high velocity air blanket between the blade and the work. This blanket of air prevents coolant from reaching the point of the cut adequately, causing the blade to cut dry.

A second cause of heat build-up is the loading of the cutting edge with silicon, causing galling and burnishing of the wafer surface.

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This gives rise to a second consideration - the prevention of thermal damage to the silicon wafer. Care must be taken in choosing the proper slicing blade or the temperature build-up at the point of contact could be excessive enough to create thermal cracks in the surface of the water.

Minimal kerf loss is also important to the wafer manufacturer who is trying to achieve the highest number of wafers from an ingot. Kerf losses of 10-12 mils are presently considered the lowest obtainable for cutting semi-conductor grade wafers. Even this kerf amounts to a 30-40% loss of the silicon at the sawing step.

The process of obtaining a flat wafer with no taper or bow, starts at the sawing operation. If the wafer is sliced as flat as possible and with little damage from the saw blade, subsequent lapping and polishing operations can be simpler and less costly. If the sawing operation is not properly executed, wafers will be produced which cannot be connected or which will break on further processing.

A final consideration that is essential to accurate slicing lies in the performance of the balde within the sawing equipment itself. Critical to making a good cut is having a blade that is vibration free, and a system which does not produce retrace damage when the blade is retracted from the workpiece. The latter becomes extremely important as the size of the wafer increases, requiring larger blades and greater throws.

MAN-MADE* Diamond for Silicon Wafer Slicing

MAN-MADE diamond products are successfully being used for slicing silicon wafers, but we at GE, are continuing to investigate system improvements. We are currently developing a silicon wafer slicing diamond that will significantly improve on the current method of wafer slicing. This MAN-MADE diamond has been specifically tailored to solve the problems of slicing silicon by exhibiting the following characteristics.

We originally discussed the elevated temperatures experienced at the silicon cutting interface. Our diamond is engineered to give quality performance at high temperatures. Such a characteristic is essential for the slicing operation due to the elevated temperatures discussed earlier. MAN-MADE diamond remains stable for several hundred degrees above the point that most bonds would break down. As an example, temperatures were measured at the tool/workpiece interface when dry grinding a high alumina ceramic material with diamond electroplated pins. These temperatures were approximately 300°C at maximum, far below any of the critical temperatures for the common electroplating bond. In addition, most wafer slicing is done wet, and special coolants are now available to prevent starvation thus alleviating the severity of any temperature problem even more.

Thermal damage was a second concern of wafer slicing operations. Our diamond has been designed with physical properties to eliminate thermal

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damage. An application utilizing the proper coolant and the appropriate type and mesh size of diamond will cause the crystal to fracture in such a way so as not to contribute to heat build-up. Tests have shown that the proper MAN-MADE* diamond produced considerably less chipping on the surface of a silicon wafer than did a similar application with mined diamond.

Kerf loss is an economic concern in slicing wafers. Use of GE diamond in a slicing saw will provide for the thinnest possible saw blade. By merit of the fact that the wafer slicing diamond is developed specifically for an electroplated application, the plating process provides the capability of making a blade to the desired thickness required for minimal kerf loss.

The next generation of VLSI circuits will require operation near the limits of resolution of optical photo-masking processes. As mentioned earlier, ultraflat wafers and masks will be required, among other things, to achieve high yields in these critical applications. It has been estimated, for example, that a one-to-one projection printer capable of reproducing one micron lines over the entire wafer will require wafer surfaces flat to within three microns. The main device for assuring as flat an initial cut as possible is to hold the blade in tension enough to prevent vibration or rubbing, which occurs when the blade wanders excessively from a straight cutting path. The proper type of adhesion between MAN-MADE diamond in a plated bond and the core of the blade is what is necessary in order to be able to withstand the extreme stress exerted on the blade during the mounting process prior to slicing.

Finally, there is little that the diamond abrasive can directly contribute to the minimization of the blade vibration and retrace damage. However, blade manufacturers continually review the basic diamond properties and with their practical experience they anticipate any changes in diamond properties which occur to specific bond and blade manufacturing techniques. As he is well informed of the diamond properties, blade manufacturing procedures, and the application details of the silicon wafer slicing operation, he can optimize the overall slicing performance.

## Conclusion

As we have seen, General Electric has historically been able to manufacture a diamond that has been specifically designed for one particular application. We have seen this in the case of RVG for tungsten carbide grinding, MBG products designed for glass grinding, EBG, a diamond designed specifically for electroplated application, and many other examples.

Currently, blade manufacturers have taken these existing product lines and have designed silicon wafer slicing blades around them. This has been done by combining their knowledge of the industry with that of blade manufacturing.

A second alternative that GE is offering is to continue the practice of their development of a new product designed specifically for one application--in this case that application is silicon wafer slicing. Product development

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is currently underway to come up with a diamond specifically for sawing silicon wafers on an electroplated blade.

In the final analysis, a proper combination of General Electric Diamond Engineering technology and the expertise of the blade manufacturer can and will continue to provide an array of superior slicing products suited to meet the ever growing needs of the semi-conductor industry.