does not have TSV's or other structures formed thereon. The reverse of the substrate with the TSV's is then ground away using abrasive pads, slurries and/or chemical etchants. The grinding process things a wafer from its initial position shown by line 30 in Fig. 3 to its final position shown by dashed line ~~32~~24. Ideally the bottom surface of a TSV will be located at the plane identified by line ~~32~~24 (see leftmost TSV bore 20) and little, if any, material filling the bore 20 will be removed as a result of the grinding. Note however that because the process of forming TSV bores 20 can be variable, it is common practice to grind to a plane/line ~~32~~24 that is closer to the obverse side of the substrate than are the nominal positions of the bottom ends of the TSV's. In this way the bottom ends of the TSV's should be uniformly exposed. Where a TSV or group of TSV's are not exposed the causes may be diverse, but for example the grinding process may inadvertently grind more heavily in one area of the substrate, thereby not exposing the TSV's in another region of the substrate or the TSV('s) may have been malformed from the beginning. In any case, once the bottom ends of the TSV's are exposed by grinding an optical inspection system is used to capture images of the TSV's. ~~AS~~As described above with respect to the top end of the TSV's, the XY position of each TSV is noted as is its geometric characteristics (diameter, shape, etc.). The array of TSV's as seen from the reverse side of the substrate may be assessed to ensure the proper placement or presence of each TSV as well as the proper pitch and alignment (skewing, etc.). The alignment step is of key importance here as it is necessary to not only localize the individual TSV's, but to also establish the position of the bottom end of the TSV with respect to the top end of the TSV to a high degree of accuracy. Presupposing that the top and bottom ends of the TSV's are each well aligned and localized with respect to their respective sides of the substrate, using the edges of the substrate as well as alignment structures formed therein (e.g. flats or notches), to ensure that respective coordinate systems of the top and bottom of the substrate are properly aligned. Alternatively, one may utilize an IR imaging system to view a structure located (e.g. fiducials, circuitry, etc.) on the obverse side of the substrate through the riverside side of the substrate simultaneously, thereby providing a direct correlation between the coordinate

[0026] In Fig. 3 the two right TSV's are too short and their bottom ends are ~~note~~not exposed at line/plane ~~32~~24 after grinding. Note that the problem of TSV's that are too deep may be correlated with larger top end diameters or with bulbous sidewalls instead of straight where the microfabrication technique that is in use (e.g. dry or wet etching) is applied for too long a time or at settings that are too strong for the given substrate. Note that a too long TSV is not necessarily problematic, i.e. it may yet function, but will represent a loss in terms of time or materials lost in extra processing or grinding. In some cases grinding may be somewhat uneven if a group of too long TSV's is sufficiently harder or tougher than the substrate in which they are formed. In this case the substrate may be ground so as to have obverse and reverse sides that are not parallel to one another.

[0027] Importantly, one ~~case~~can see that the right two TSV's in Fig. 3 are not symmetrical about an axis normal to the obverse and reverse sides of the substrate. This can be due to misalignment of microfabrication tools or by the movement means being itself misaligned or perhaps where a debris of some type is interposed between the substrate and the movement means. Again, this type of misalignment may not rule out the use of a substrate so long as the TSV's retain sufficient placement accuracy to make the required electrical connections in a semiconductor device package.

[0028] Fig. 4 illustrates a basic assessment of the magnitude of an offset between the position and geometry of the top and bottom of a TSV. Top 40 of the TSV is larger than the bottom 42. Also the bottom 42 of the TSV is smaller than the top 40. That the two ends 40, 42 are laterally offset suggests that a microfabrication tool may be misaligned or that there is debris between the substrate and the movement means on which it is supported. Depending on the desired geometry of the TSV and on the nature of the microfabrication tooling or process used, that the sizes of the top 40 and bottom 42 differ may also be indicative of the nature operation of a microfabrication tool or process. While the TSV pictured in Fig. 4 has top and bottom ends with a circular shape which together with the size difference therebetween infer a more or less frustoconical shape, it is to be understood

that the TSV take on other cross section shapes such as pyramidal in which case the shapes of the top and bottom ends of the TSV may be square or rectangular.

[0029] As can be seen in Fig. 5, it is possible for a TSV to have a somewhat irregular shape. Ideally however, the shape of the TSV will be regular and the degree to which the shape of the top and bottom ends of the TSV depart from the pre-defined or desired regular shape may define how well a microfabrication tool or process is functioning. Note that because the top 44 and bottom 46 ends of the TSV are irregular in shape, one may use software means such as blob analysis software to determine a centroid of the top or bottom area as suggested by the figure. The centroids may then be used to determine lateral offsets Xo and Yo as shown.

[0030] As described above, interferometers may be used to characterize TSV's and other structures including a substrate S such as a wafer. Examples of interferometers suitable for this purpose are illustrated in Figs. 6 and 7.

[0031] Fig. 6 illustrates one embodiment of an interferometer ~~10~~110 that may benefit from the application of principles disclosed herein. Fig. 7 illustrates another, similar interferometer ~~10'~~110' that may also benefit from the application of principles disclosed herein.

[0032] In Figs. 6 and 7 multi-spectral or broadband illumination is emitted from a light source ~~20~~120. The light source may be a simple broadband source such as a halogen, xenon, fluorescent or incandescent or similar. Essentially any light source that emits whatever wavelengths of light needed for a specific application will suffice. The interferometers 110 and 110' collect and conduct light emitted from the light sources 120 by means of fiber optic cables 122. Note that light emitted from sources 120 may propagate through open air in lieu of cables 122.

[0033] In both interferometers 110 and 110' light from source 120 is emitted along optical path 124. In the case of interferometer 110 in Fig. 6, light passes through a beam splitter 121 before being emitted onto the optical path 124. Optical element 126, which may include one or more lenses, filters or stops, collimates the light traveling along optical path

signal output by the spectrometer can be relatively low due to the lack of light. This may result in a poor measurement where the signal to noise ratio is particularly low.

[0038] The interferometer 110' illustrated in Fig. 7 overcomes poor signal to noise ratios by omitting the beam splitter 121 and locating the sensor leg of the interferometer 110' adjacent to the beam splitter 128. This modification results in a slightly larger optomechanical package, however the spectroscope 132 may yet be located remotely where a fiber optic cable ~~23~~123 is used.

[0039] Balancing of intensities[1]

[0040] It has been noted in the literature that signals having dissimilar magnitudes may yet interfere with one another to product an interference signal or fringe. However in certain circumstances, as will be described in more detail hereinbelow, it can be desirable to maximize interference in a system such as that shown in Figs. 6 and 7.

[0041] In the reference leg of an interferometer such as interferometers 110 and 110', a reflector of some sort is used to return light diverted along optical path 125 to the beam splitter 128. In Figs. 6 and 7 this reflector is represented by a generic mirror 129, though other options are available as will again be described in more detail hereinbelow. Generally speaking, a ~~mirror1 29~~mirror 129 has a high reflectance and will return a large percentage of the light incident upon it along optical path 125. The same cannot always be said for the substrate S. Where there is a reflectance mismatch between the surface of the substrate S and the mirror 129, the resulting interference signal may not be optimal. Accordingly, it may be advantageous to match, at least to a degree, the magnitude of the signals that are joined by the beam splitter 128.

[0042] Matching the magnitude of the signals joined by the beam splitter 128 may be effected by attenuating the light on one of the optical paths 124, 125 or by modifying how the beam splitter 128 divides light from the light source 120 along paths 124, 125. Where

[1] http://www.rp-photonics.com/spotlight_2009_05_22.html

the signal to noise ratio is sufficiently high, one may attenuate light on one of the optical paths 124, 125 such that the amount of light from each path that contributes to the interferred light signal provided to the spectroscope 132 is within a predetermined range of proportions. In one exemplary embodiment, the amount of light reaching the spectrometer from each optical path 124, 125 is approximately the same. Note that by attenuating light along one of the optical paths 124, 125 the magnitude of light reaching the spectrometer 132 will be lower and it is more likely that a less useful signal may be derived therefrom.

[0043] In one embodiment light traveling along optical path 125 is attenuated by placing a neutral density filter 136 along the optical path 125. In a preferred embodiment, the neutral density filter 136 is part of a modifiable filter apparatus (not shown) of a useful type. For example, the neutral density filter 136 may simple be one of a number of different filters in a filter wheel. By modifying the position of the filter wheel one may select a suitable neutral density filter 136. In another example, the neutral density filter 136 may be mounted in a holder that permits manual replacement of the filter to select an appropriate attenuation of light along the optical path 125. In yet another example, one may use a modifiable spatial light modulator as a neutral density filter 136. A spatial light modulator is an LCD device that can modify the amplitude, phase, or polarization of light waves in space and time. Note that the neutral density filter 136 may be positioned in one or both of optical paths 124 and 125.

[0044] In another embodiment, a fixed neutral density filter 136 may be used in one or both of the optical paths 124 and 125. Generally speaking, where the interferometer 110 or 110' is to be used in a setting in which there is a high rate of turnover in the substrates S such that optimization or balancing of the magnitudes of the light returned from the respective optical paths 124, 125 must change frequently, it is more likely that a modifiable filter 136 would be suitable. Conversely, where the nature of the substrates S is fairly consistent, then a fixed filter 136 may be suitable. One will appreciate that the increased complexity of modifiable filters 136 will increase the cost and complexity of the

minimize the extent of the aforementioned null zones by introducing into the respective legs of an interferometer a differential chromatism, i.e. a quantized chromatic aberration in each leg that differs between the legs. It is to be understood that a "different" chromatic aberration may be introduced into either leg of an interferometric optical system and that the examples below are not limiting in this way.

[0048] Figs. 8a-8c illustrate schematically three ways in which differential chromatism may be imposed upon an interferometric optical system. Note that the reference leg variations illustrated in Figs. 8a-8c and variations thereof may form part of optical path ~~25~~125 of an interferometer 110 or 110' (Figs. 6 and 7). Fig. 8a illustrates a first embodiment of a reference leg 140 of an interferometer. Reference leg 140 receives light from a beam splitter (not shown) such as beam splitter 128. This light is directed along optical path 125 to a reflector 129. In this embodiment light is focused onto the reflector 129 by an optical element 142. Light reflected by reflector 129 is collimated and returned along optical path 125 towards the beam splitter (not shown) that directed light along optical path 125 in the first instance. At least a portion of the light returned along optical path 125 passes through the beam splitter (not shown) and then on to the spectrometer 130. The optical path 125 in the embodiment of Fig. 8a includes an optional turning mirror 144 that is useful for optomechanically fitting the interferometer 110, 110' into a given space.

[0049] The optical element 142 shown in Fig. 8a may have substantially the same chromatic aberration as an objective placed in the sample leg of an interferometer, in which case the effects of chromatic aberration on interferometric measurements is reduced but the problem of null zones is increased. Alternatively, the optical element 142, which may consist of one or more individual lenses, filters or stops, may have a different amount of chromatic aberration than the objective of the reference leg, i.e. may induce differential chromatic aberration. In this latter case chromatic aberration may be increased, but null zones are minimized. Generally speaking a reflector 129 will not induce much in the way of chromatic aberration. That being said, it is preferable to take into consideration the

possibility that coatings or the like on the reflector 129, alone or in combination with the optical element 142, may define a different chromatic aberration than either of the reflector or optical element taken alone.

[0050] Fig. 8b illustrates a reference leg 140 that utilizes a reflector cube or retroreflector 144 to return light along the optical path 125 without introducing much, if any chromatic aberration to the returned light. In this instance differential chromatism is induced by using an objective having a known chromatic aberration in the sample leg of an interferometer. Since the retroreflector 144 induces little, if any chromatic aberration, the resulting interferometer is said to exhibit differential chromatism between its reference and sample legs.

[0051] Fig. 8c illustrates a reference leg ~~40~~140 that incorporates the use of a mirror 146 having a predetermined optical power to return light along optical path 125. Mirror 146 reflects and focuses light onto mirror 147 which returns the light to mirror 146 which in turn collimates and returns the light to the beam splitter. Note that the exact optical power is highly dependent upon the optical system in which it is utilized and accordingly, no explicit example is provided here. The exact power and placement of a mirror 146 having optical power may easily be determined by one skilled in the art of optical design using classical or numerical automated optical design techniques.

[0052] Fig. 9 is a schematic representation of an interferogram, which relates the intensity of interference fringes sensed by the interferometer 110, 110' to the wavelength of the interfering light. Note that this interferogram is obtained at given position of the interferometer relative to the substrate S. As will be appreciated, the position of the interferometer is fixed relative to the substrate and it is the position of features of the substrate S that vary with respect to their position along the optical path 124.

[0053] In one embodiment of the present invention, the spectrum of light used by the interferometer 110, 110' includes infrared wavelengths and accordingly, in addition to being capable of localizing an upper surface of a substrate S made of silicon, the

interferometer is capable of localizing features within the silicon substrate S. One such structure may be, for example, a bottom surface of a TSV as described hereinabove.

[0054] As can be seen in Fig. 9, there exists a null value or space 150 in the intensity data at approximately 612 nm. This null value 150 is a result of a lack of interference at the specified wavelength range. This position and extent of this null value 150 depends upon the nature of the optical system that forms the interferometer 110 or 110' and the nature of the substrate S. Where this null value 150 is wide, it can be difficult to obtain information that is necessary to properly localize and characterize the substrate S that is under test. Where the reference leg and sample legs of the interferometers 110 and 110’ have substantially the same chromatic aberration, i.e. where the differential chromatism of the respective legs is minimized, the null value 150 extends over a relatively larger area. Such an interferometer 110 or 110’ subsequently has a gap in its output that makes it more difficult to fully characterize a substrate S. Introducing a specified amount of differential chromatism minimizes or in some instances, practically eliminates the null value 150 and improves the performance of the interferometer 110 or 110’.

[0055] Another problem that may be caused by the null value 150 is where this gap in the useful data obtained from the spectrometer ~~30~~132 corresponds to positions, structures or characteristics that are of interest on the substrate S. It has been found that by modifying the input and output apertures 152, 154 of the interferometers 110, 110’, one may be able to move the null value 150 to a position that is outside of the desired range of sensitivity or to at least move it to a location where the negative effects of the null value 150 are minimized. Making the apertures 152, 154 larger or smaller may move the position of the null value 150 to the left or the right on the graph shown in Fig. 9. Where the structures of interest on the substrate S are typically identified or characterized at the wavelengths to the right or left of the null value 150, a more reliable and certain measurement may be obtained.

CLAIMS

What is claimed is:

1. A method of assessing a quality level of a through silicon via (TSV) formed in a substrate comprising:

obtaining geometric information about a top end of a TSV from~~at~~ an obverse side of the substrate;

obtaining geometric information about a bottom end of a TSV from~~at~~ a reverse side of the substrate;

aligning the geometric information of the top and bottom ends of the TSV to determine an alignment of the respective top and bottom ends of the TSV.

2. The method of assessing a quality level of a through silicon via (TSV) of claim 1 further comprising obtaining a thickness value of the substrate substantially at an XY position of the TSV and inferring a geometric volume of the TSV based at least on the geometric information of the respective top and bottom ends of the TSV and determining whether the inferred geometric volume of the TSV is similar to a predetermined criteria.

3. A method of characterizing a microfabrication process and a product formed by the microfabrication process comprising:

determining a location of a plurality TSV's from~~at~~ an obverse side of a substrate;

determining a location of the same plurality of TSV's from~~at~~ a reverse side of a substrate; and,

determining the presence of a misalignment between the position of a TSV from~~at~~ the obverse and reverse sides of the substrate to identify a process excursion in a microfabrication process.

4. The method of characterizing a microfabrication process and a product formed by the microfabrication process of claim 3 further comprising:

determining a geometry of the plurality of TSV's from~~at~~ both the obverse and reverse sides of the substrate; and,

determining whether the geometry of the respective TSV's from~~at~~ the respective obverse and reverse sides of the substrate varies by more than a predetermined criteria selected from a group consisting of size and geometry.

5. The method of characterizing a microfabrication process and a product formed by the microfabrication process of claim 3 further comprising:

fitting the location of the plurality of TSV's as determined from~~at~~ the obverse side of the substrate to the location of the plurality of TSV's as determined from~~at~~ the reverse side of the substrate; and,

quantifying the degree of misalignment between the fitted locations of the TSV's, if any.

6. The method of characterizing a microfabrication process and a product formed by the microfabrication process of claim 3 wherein determining a location of a plurality TSV's from~~at~~ an obverse side of a substrate is conducted prior to the filling of the TSV with a conductive material (metallization).

7. The method of characterizing a microfabrication process and a product formed by the microfabrication process of claim 3 wherein determining a location of the same plurality of TSV's from~~at~~ a reverse side of a substrate is carried out after the substrate has been thinned from a nominal thickness.

8. A method of characterizing a microfabrication process and a product formed by the microfabrication process comprising:

determining a location of a plurality TSV's from~~at~~ an obverse side of a substrate;

determining a location of a bottom end of the same plurality of TSV's within a substrate; and,

determining the presence of a misalignment between the position of a TSV from~~at~~ the obverse side of the substrate and the position of the bottom end of the TSV within the substrate to identify a process excursion in a microfabrication process.

9. The method of characterizing a microfabrication process and a product formed by the microfabrication process of claim 8 further comprising the use of radiation in the near infrared range of wavelengths to obtain a position of the bottom end of the TSV's.

10. An interferometer for characterizing wafers and processes that modify wafers comprising:

a broadband source of light, the output of which is directed along a first optical path toward a substrate that is to be characterized;

a beam splitter positioned along the first optical path which directs at least a portion of light from the first optical path to a second optical path;

an objective for focusing light propagation along the first optical path onto the substrate, the objective collecting and returning light from the substrate along the first optical path to the beam splitter which directs at least a portion of the light returned from the substrate onto a third optical path;

an optical device for reflecting light propagating on the second optical path back to the beam splitter which passes at least a portion thereof onto the third optical path, the optical device having a characteristic chromatic aberration that differs by a predetermined amount for a predetermined range of