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(54) **Title:** AUTOMATED INLINE INSPECTION OF WAFER EDGE STRAIN PROFILES USING RAPID PHOTOREFLECTANCE SPECTROSCOPY

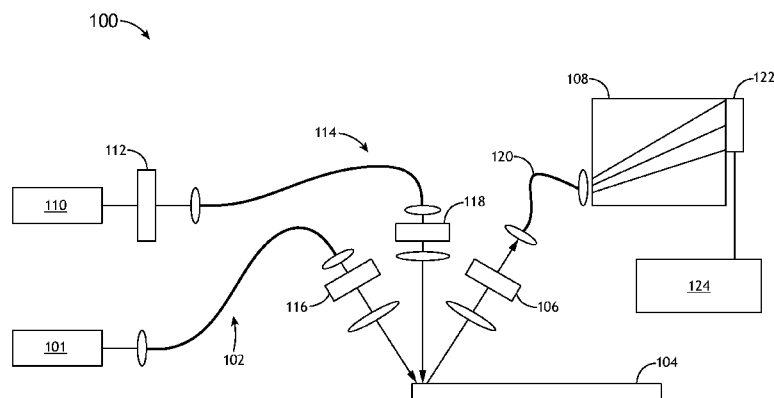


FIG. 1

(57) **Abstract:** Photoreflectance spectroscopy is used to measure strain at or near the edge of a wafer in a production process. The strain measurement is used to anticipate defects and make prospective corrections in later stages of the production process. Strain measurements are used to associate various production steps with defects to enhance later production processes.

AUTOMATED INLINE INSPECTION OF WAFER EDGE STRAIN PROFILES USING RAPID
PHOTOREFLECTANCE SPECTROSCOPY

PRIORITY

[0001] The present application claims the benefit under 35 U.S.C. § 119(e) of United States Provisional Application Serial Number 61/982,196, filed April 21, 2014, and United States Provisional Application Serial Number 62/057,126, filed September 29, 2014, both of which are incorporated herein by reference.

FIELD OF THE INVENTION

[0002] The present invention is directed generally toward photoreflectance (PR), and more particularly to PR for strain measurement in silicon wafers.

BACKGROUND

[0003] Photoreflectance (PR) and piezoreflectance (PzR) of substrates such as silicon-germanium (SiGe), gallium arsenide (GaAs), indium gallium sulfide (InGaS) exhibit a typical band gap of approximately 1.5eV or 3.5eV.

[0004] Rapid PR (RPR) spectroscopy requires the simultaneous detection of a small modulated reflectance (ΔR) signal and a large time-invariant, unmodulated reflectance signal R , and the relation of the small modulated reflectance and unmodulated reflectance ($\Delta R/R$). Even at parts of the spectrum where it is significant, ΔR is relatively small compared to the unmodulated reflectance R , of the

order of several to hundreds parts per million. Various sources of optical and electrical noises will be present and these dominate the ΔR signal. However, the ΔR signal is always present at the known modulation frequency and so methods of frequency-discriminating signal recovery are typically employed to detect a signal at this known frequency. Therefore, phase sensitive lock-in amplification was required for the measurement of the ΔR signal in PR spectroscopy and the measurement was to be made at different times for each wavelength, so that the $\Delta R/R$ spectrum was therefore generally recorded in a serial spectral mode. This limits the practical speed of the PR measurement and precludes its widespread industrial application in high-speed production line inspection of semiconductor wafers.

[0005] Strained silicon (sSi) refers to silicon in which strain is engineered locally in a device structure or globally across a wafer by a local or global stress to accelerate electrons, which allows manufacture of faster devices. Faster sSi transistors due to increased electron mobility and velocity have already been proven. As a result, the technology of strain engineering is being widely used to speed carrier mobility in transistor channels in order to increase the drive currents.

[0006] Globally sSi on a wafer comprises a very thin layer of single-crystal silicon strained by pseudomorphic growth up to a critical thickness on a relaxed $\text{Si}_x\text{Ge}_{1-x}$ stressing layer of wider lattice constant dependent on the Ge mole fraction x .

[0007] In all global sSi technologies with one exception, the strain in the silicon is described as biaxial, the result of two effects, namely, the expansion of the silicon lattice due to the wider lattice constant of the relaxed $\text{Si}_{1-x}\text{Ge}_x$ layer, which is tensile stressing it, and the contraction of the silicon lattice in the vertical direction because of its behavior as a near-perfect Poisson solid. These two strain effects, hydrostatic tension, and uniaxial compression, will be presently shown to be mirrored by two

competing effects in the electronic band structure in the vicinity of the E_1 critical point of silicon, whose combined effect is measurable by PR spectroscopy. Such a sSi layer can be transferred onto an SiO₂ buried oxide layer while retaining the strain to form a strained silicon-on-insulator (SSOI) wafer.

[0008] X-ray diffractometry (XRD) and Raman spectroscopy (RS) have been used for strain measurement in silicon. XRD suffers from excessive measurement time, and RS has poor resolution. Other optical inspection techniques look for slip-lines on the surface or cracks in the edge of silicon wafers. Optical inspection methods detect defects rather than measuring strain and are therefore unsuitable for identifying problems before defects occur, controlling strain sources, relating strain defects to specific process parameters, or managing strain levels in wafers.

[0009] Consequently, it would be advantageous if an apparatus existed that is suitable for directly measuring strain in a wafer production process in time to apply the measurements to prevent defects.

SUMMARY

[0010] Accordingly, the present invention is directed to a novel method and apparatus for directly measuring strain in a wafer production process in time to apply the measurements to prevent defects.

[0011] In at least one embodiment of the present disclosure, PR spectroscopy is used to measure strain at or near the edge of a wafer in a production process. The strain measurement is used to anticipate defects and make prospective corrections in later stages of the production process. In another embodiment, strain measurements are used to associate various production steps with defects to enhance later production processes.

[0012] It is to be understood that both the foregoing general description and the following detailed description are exemplary and explanatory only and are not restrictive of the invention claimed. The accompanying drawings, which are incorporated in and constitute a part of the specification, illustrate an embodiment of the invention and together with the general description, serve to explain the principles.

BRIEF DESCRIPTION OF THE DRAWINGS

[0013] The numerous advantages of the present invention may be better understood by those skilled in the art by reference to the accompanying figures in which:

FIG. 1 shows a block diagram of a system according to one embodiment of the present invention for implementing RPR in a wafer fabrication process for edge strain measurement;

FIG. 2 shows an environmental representation of one embodiment of the present invention;

FIG. 3 shows an environmental representation of one embodiment of the present invention;

FIG. 4 shows a block diagram for a computer system according to one embodiment of the present invention;

FIG. 5 shows a flowchart of a method for edge strain measurement;

FIG. 6 shows optical elements in an embodiment of the present invention;

FIG. 7 shows a block diagram according to another embodiment of the present invention for implementing RPR in a wafer fabrication process.

DETAILED DESCRIPTION

[0014] Reference will now be made in detail to the subject matter disclosed, which is illustrated in the accompanying drawings. The scope of the invention is limited only by the claims; numerous alternatives, modifications and equivalents are encompassed. For the purpose of clarity, technical material that is known in the technical fields related to the embodiments has not been described in detail to avoid unnecessarily obscuring the description.

[0015] An understanding of embodiments of the present disclosure may be further illuminated by U.S. Patent No. 7,623,228, U.S. Patent No. 7,659,979, and U.S. Patent App. Pub. No. 2013/0003050, all of which are hereby incorporated by reference.

[0016] PR spectroscopy provides a useful alternative to XRD and RS to meet the requirements for a nondestructive in-line strain metrology tool. Rapid PR (RPR), and specifically micro RPR (μ RPR), provides a measurement of strain in sSi with a high degree of accuracy in a sufficiently short time for application as an on-line production quality assurance tool.

[0017] Embodiments of the present invention measure local wafer strain and local/global strain profiles on and near the edge of a silicon wafer based on μ RPR methods. Such measurements allow for monitoring and management of the resulting impact of wafer edge strain on process yield and health.

[0018] Rapid thermal processing (RTP) of silicon wafers can lead to various forms of residual strain in the wafers. For example, the silicon wafer and wafer carrier heat-up and cool-down at different rates. As a result, the contact points

between the silicon wafer and the wafer carrier can cause a local thermal gradient in the wafer that results in a corresponding thermally induced local residual strain that remains after the wafer cooled. Under some conditions, the residual strain is local and on a microscopic scale can exceed the yield strength of silicon. This may result in lattice defects such as slip dislocations and micro-cracks. These defects are undesirable both in terms of device yield and process health. Slip dislocations may induce slip line defects in surface films that propagate with further processing and compromise yield. Micro-cracks can lead to wafer breakage during further processing that can damage expensive processing equipment and reduce process throughput.

[0019] Measurement of wafer strain at/near the wafer edge provides insight into the status of a wafer's slip dislocations or susceptibility to developing slip dislocations, strain-related micro-cracking or susceptibility to developing micro-cracks, and susceptibility to strain-related wafer breakage.

[0020] Referring to FIG. 1, a block diagram of a system 100 according to one embodiment of the present disclosure for implementing RPR in a wafer fabrication process for edge strain measurement is shown. In one embodiment, a probe light source 101 generates an incident probe beam and directs the incident beam through optical components 102, including fiber optics, onto an edge of a sample 104. In one embodiment, the incident light passes through an incident filter 116 to deliver a blue ultraviolet (UV) beam to the edge of the sample 104. Contemporaneously, a perturbation is optically applied to the edge of the sample 104 by a modulated pump beam. The modulated pump beam is produced by a pump laser 110, with the pump laser 110 beam passing through a modulator 112, such as a mechanical chopper, and modulated pump beam optical components 114 to the edge of the sample 104. In one embodiment, the modulated pump beam may be filtered by a pump beam filter 118

to a desirable frequency range. The reflectance of the edge of the sample 104 is altered by photoinjection of charge carriers via the interaction of the incident beam and modulated pump beam. In another embodiment, the modulated reflected incident beam may pass through a spectrograph filter 106 to filter the modulated reflected incident beam to a bandpass region of the spectrum in the region of the E_1 transition of silicon at approximately 3.4 eV. In another embodiment, the modulated reflected incident beam is transmitted through receiving optical components 120 and dispersed into its constituent wavelengths by a spectrograph 108 and the constituent components are sampled by a detector 122. In another embodiment, a processor 124 connected to the detector 122 analyzes the spectrographic data to measure wafer strain in-line in sSi wafers including SSOI and silicon-germanium on insulator by measuring the direct bandgap energy of the sSi layer and converting the value to strain using a theoretical model.

[0021] In another embodiment, the processor 124 reads the modulated reflectance ΔR signal as well as the unmodulated reflectance R signal from each pixel of the detector 122 in sufficiently rapid succession such that multiple measurements of the ΔR signal can be made within a single period of the modulation cycle. In this way, the system allows the simultaneous measurement of the PR signal at all wavelengths in parallel by means of multiplexing the readout. The acquisition time for the entire spectrum is approximately 1-2 ms (e.g., 1.03 ms). Depending on the measured structures, the acquisition may be averaged a plurality of times in order to improve the signal to noise ratio.

[0022] By way of example, in the case of a typical 200 Å top strained silicon layer thickness SSOI wafer, measured over the spectral range of the Si direct bandgap energy of 2.8 to 3.7 eV during a 10 s duration, and fitted to a summation of two low

field PR line shapes, the RPR spectrum is modeled using an approximation based on the third derivative functional form, in which the critical point dimensionality is 2-d, and index parameter $m=3$, the RPR spectrum model may be defined by:

$$\frac{\Delta R}{R_{PR}}(E) = \text{Re} \left[A e^{i\theta} (E - E_g + i\Gamma)^{-3} \right]$$

[0023] It is noted that this model is appropriate given the negligible electro-optic effect and absence of Franz-Keldysh oscillations in the silicon PR spectra. Here, A is an amplitude factor, θ is a line shape phase factor, E_g is the bandgap energy, and Γ is the broadening energy parameter. The two transitions may be measured by fitting the RPR spectrum to correspond to the light hole (LH) and heavy hole (HH) direct bandgaps. It is noted that hydrostatic tensile strain may shift the interband transition (L band) energy, while compressive uniaxial strain along an axis normal to the wafer lifts the degeneracy of the valence band, leading to split LH and HH bands, and a splitting of the transition.

[0024] The behavior of the energy shift ΔE of the E_1 and associated transitions under hydrostatic strain and splitting in the energy shift due to uniaxial strain contribution have been described by a relationship based on extensive analysis of the electroreflectance response of silicon under uniaxial stress:

$$\Delta E = \sqrt{1/3} D_1^1(\varepsilon_{\perp} + 2\varepsilon_{\parallel}) \pm \sqrt{2/3} D_3^3(\varepsilon_{\perp} + \varepsilon_{\parallel})$$

where the $\pm$ sign implies addition to obtain the shift in the HH and LH branches, $\varepsilon_{\perp}$ is strain perpendicular to growth, $\varepsilon_{\parallel}$ is strain in-plane, D_1^1 is the hydrostatic deformation

potential, measured by Kondo and Moritani as -9.8 eV, and D_3^3 is the intraband strain deformation parameter along the direction perpendicular to growth, having a value of 4.7 eV. The relationship may therefore be rewritten as:

$$\Delta E = -5.658(\varepsilon_{\perp} + 2\varepsilon_{\parallel}) \pm 3.837(\varepsilon_{\perp} + \varepsilon_{\parallel})$$

[0025] The strain tensor elements perpendicular to growth take the form:

$$\begin{aligned}\varepsilon_{xx} = \varepsilon_{yy} = \varepsilon_{\parallel} &= \frac{a_0(Si_{1-x}Ge_x) - a_0(Si)}{a_0(Si)}, \\ \varepsilon_{zz} = \varepsilon_{\perp} &= -2 \frac{C_{12}}{C_{11}} \varepsilon_{\parallel}, \\ \varepsilon_{xy} = \varepsilon_{xz} = \varepsilon_{yz} &= 0\end{aligned}$$

where x is the germanium concentration, C_{11} and C_{12} are the elastic constants, and the Bir-Pikus Hamiltonian for a G1 type band having the form:

$$a_0(Si_{1-x}Ge_x) = a_0(Si) + 0.200326x(1-x) + [a_0(Ge) - a_0(Si)]x^2$$

Therefore the lower energy branch of the split transition shifts according to:

$$\Delta E = E_{LH} - 3.4 = -0.1375\varepsilon_{\parallel}(\text{eV})$$

where $\varepsilon_{\parallel}$ is expressed in percentage strain. As a result, the strain value is calculated using the bandgap shift of the E_{LH} transition compared to the unstrained silicon direct bandgap 3.4 eV. It is conventional to quote the tensile strain in the plane of the wafer.

[0026] RPR results may be compared to RS. Actual calibration against a range of RS values gives a calibration result of 3.399 and -0.1368 eV as unstrained silicon bandgap and conversion factor, respectively.

[0027] PR techniques may be used to measure tensile in-plane edge strain in biaxially strained SSOI wafers. A decrease in the acquisition time by a factor of 100 to 500 may be achieved for a nondestructive technique suitable for in-line sSi metrology. A decrease and split (E_{LH} and E_{HH}) in the silicon bandgap have been observed upon tensile strain. Based on theoretical models, the E_{LH} transition value may be converted to biaxial tensile strain, which is consistent with RS results.

[0028] Referring to FIG. 2, an environmental representation of one embodiment of the present disclosure is shown. In one embodiment, strain measurements taken at or near the edge of a wafer 224 are made with an optical scanning system 200 as described herein. In another embodiment, the optical axis 206 of the optical scanning system 200 is maintained substantially normal to the portion of the surface of the wafer 202 where the measurement is made. In addition, the portion of the surface of the wafer 204 where the measurement is made is maintained substantially at the optimal focus position of the optical scanning system 200 throughout the entire trajectory 202 traveled by the optical scanning system 200. It is noted that maintain optimal (or adequate) focus may be accomplished using the optically measured wafer edge profiles for feed-forward to wafer r and z stages or any other metrics necessary to maintain focus and normality of the optical axis 206 even where the edge is irregular.

[0029] The feed-forward procedure may be combined with a real-time auto-focus mechanism to mitigate errors in the measurement of the wafer 204 edge

profile. Alternatively, the feed-forward procedure may be replaced with a combined real-time auto-focus mechanism and default wafer profile. For example, a semi-circle or other pattern may be used for the wafer edge profile.

[0030] Referring to FIG. 3, an environmental representation of one embodiment of the present invention is shown. In one embodiment, a wafer 304 in a production process may be inspected by various inspection modules 300, 306. In one embodiment, module 300 includes an edge inspection module. In another embodiment, module 306 includes a μ RPR edge strain measurement module 306. In one embodiment, the μ RPR strain measurement module 306 may measure strain at sample spot sizes 302 of several millimeters down to less than 10 micro-meters. In another embodiment, the μ RPR strain measurement module 306 may sample wafer 304 edge locations as the wafer 304 moves. Alternatively, the μ RPR strain measurement module 306 may take measurements in a continuous fashion, repeatedly, over a track defined by an edge profile. Multiple tracks may be measured serially or in parallel. The μ RPR edge strain measurement module 306 may include a time-delay integration (TDI) sensor for performing the actual image collection. Furthermore, because the μ RPR strain measurement module 306 collects both modulated and unmodulated light reflected from the wafer 304, a modulating pump beam source may be periodically turned on and off to modulate an incident beam at a given sampling rate.

[0031] It is noted that the μ RPR optics head may provide for multiple simultaneous measurement points as a means to increase throughput and mitigate laser damage. In one embodiment, the μ RPR optics head may be on a dedicated wafer inspection system, or may be integrated into a wafer inspection platform with multiple inspection systems. In another embodiment, the μ RPR may be mounted such

that a step-wise or continuous measurement is made of a specific zone circumference of the wafer.

[0032] Referring to FIG. 4, a block diagram for a computer system according to one embodiment of the present invention is shown. In one embodiment, the computer system 400 includes a processor 422, memory 404 connected to the processor 422 for storing computer executable code, and a data storage element 406 for storing wafer profile data. In another embodiment, a spectral detector 424, such as a TDI sensor, is connected to the processor 422 to receive reflected light from the edge of a wafer and modulated reflected light from the edge of the wafer via a spectrograph.

[0033] In a wafer production process, the edge of a spinning wafer may be inspected for strain. In one embodiment, an illumination device may provide an incident beam arranged to illuminate a portion of the wafer. The incident beam is then reflected to a spectrograph for detection by the spectral detector 424. In another embodiment, the illumination device may also include a pump laser to produce a modulation beam that illuminates the portion of the wafer to produce a modulated incident beam reflected to the spectrograph for detection by the spectral detector 424.

[0034] In one embodiment, the processor 422 receives spectral data and produces a strain measurement associated with the illuminated portion of the wafer, the illuminated portion being a surface on the or about the edge of the wafer. In another embodiment, the processor 422 may adjust the location and orientation of the spectral detector 424 based on an edge profile stored in the data storage element 406, or a predetermined spot locations where strain measurements are desirable. Based on the strain measurements, the processor 422 may determine that a defect is

likely in the production process or that a strain threshold for a portion of the wafer has been reached. Furthermore, given known production process parameters, the processor 422 may determine that strain related defects in the edge of a wafer may be correlated to such parameters; for example, temperature disparities during the production process.

[0035] Local and global strain profiles on or near a wafer edge may allow the processor 422 to identify problematic strain profiles before defects or micro-cracks appear, or at least identify wafers that may already have developed strain-related defects; control strain-related defects such as slip lines and micro-cracks at or near the edge of the wafer; identify and control strain sources; and manage strain level in wafers.

[0036] Multiple μ RPR strain measurements can be made on a wafer in a stepwise or continuous fashion about the circumference of the wafer. For example, measurements may be made of a top edge surface, bottom edge surface, and side surface of an edge of the wafer, and may incorporate care areas and/or exclusion zones for the measurement. Multiple μ RPR strain measurements may be post-processed to generate a continuous strain profile at virtually any scale; e.g. globally such as around the circumference of the top edge, side edge, and bottom edge of the wafer down to a local region whose smallest size is limited by the sample spot size.

[0037] Referring to FIG. 5, a flowchart depicting a method for edge strain measurement is shown. In a first step 500, a wafer (e.g., silicon wafer) is loaded into a wafer production apparatus. For example, the production apparatus may include, but is not limited to, an embodiment of the present disclosure. In a second step 502, the wafer is aligned for edge inspection. In a third step, the wafer production

apparatus then measures 504 an edge profile of the wafer. In a fourth step 506, the wafer production apparatus performs a strain measurement on an edge surface of the wafer. For example, the measurements may include, but are not limited to, spot measurements or continuous measurements. In another embodiment, the wafer production apparatus may track multiple parameters when performing the strain measurements; such parameters may include identifying particular areas of interest for spot measurement, particular areas identified via previous production processes that are prone to strain related defects, monitoring strain values for a pre-determined threshold, or SNR parameters. In a fifth step 508, the wafer production apparatus may modify a feature of the wafer production process based on the edge strain measurements.

[0038] Embodiments of the present disclosure may have an edge strain measurement resolution of better than 0.1%, a silicon yield stress of approximately 1 GPa at room temperature and approximately 10 GPa at 1000 °C, and a Young's modulus of approximately 130.

[0039] Referring to FIG. 6, optical elements of an embodiment of the present disclosure are shown. In one embodiment, the edge of a spinning wafer 622 in a wafer production process is illuminated. For example, as shown in FIG. 6, a white probe light may illuminate the wafer and scan the wafer along a selected spatial scan direction. In another embodiment, the reflected illuminated light may be collimated by a first curved mirror 602 and reflected onto a diffraction grating 604. In one embodiment, the diffraction grating 604 reflects a diffracted image from the edge of the spinning wafer 622 to a second curved mirror 606 that focuses the diffracted image onto a TDI sensor 608. As shown in FIG. 6, light received by the TDI sensor 608 may be across the sensor as a function of wavelength, with the scanning direction

being arranged orthogonal to this direction. In another embodiment, data from the TDI sensor 608 is used to determine a strain measurement associated with the edge of the spinning wafer 622.

[0040] Referring to FIG. 7, a block diagram according to another embodiment of the present disclosure for implementing RPR in a wafer fabrication process is shown. In one embodiment, a reference beam 700, such as a reference laser beam (e.g., reference laser suitable for AF), passes through optical elements 702, 704, 706, 708, 712 to the edge of a wafer 722. Contemporaneously, a pump beam 710, such as an S-wave pump beam, passes through the same optical elements 702, 704, 706, 708, 712 to the same spot on the edge of the wafer 722.

[0041] In one embodiment, optical element 708 includes one or more prisms 708 (e.g., beam separation prism) for directing the reference beam 700 and pump beam 710 along a common entrance path. In another embodiment, optical element 712 includes a first beam splitter 712 (e.g., polarized beam splitter or GLAN-type beam splitter) for reflecting the reference beam 700 and pump beam 710 to a first mirror 702.

[0042] For example, the first mirror 702 may be, but is not required to be, a convex mirror for reflecting the reference beam 700 and pump beam 710 to a second mirror 704 and third mirror 706 respectively. By way of another example, the second mirror 704 and third mirror 706 may be, but are not required to be, concave mirrors for focusing the reference beam 700 and pump beam 710 to a particular portion of the edge of the wafer 722. In another embodiment, the second mirror 704 and third mirror 706 may be arranged so as to focus the reference beam 700 and pump beam 710 onto the wafer 722 from different angles.

[0043] In at least one embodiment, a P-wave illuminator 714 may introduce a probe beam to a second beam splitter 716 (e.g., 50/50 beam splitter), which directs a portion of the probe beam through one or more optical elements 702, 704, 706, 712 to combine with the reference beam 700 and pump beam 710.

[0044] In another embodiment, light reflected from the wafer 722 traverses one or more of the optical elements 702, 704, 706 through the first beam splitter 712 and the second beam splitter 716 to a detector 724. In at least one embodiment, a slit diffraction element 718 (e.g., slight has long width aligned with TDI) and a band-pass filter 720 may be interposed between the second beam splitter 716 and the TDI detector 724.

[0045] Embodiments of the present invention provide a means to measure and control wafer edge strain, in-line, before associated defects and adverse consequences occur as described.

[0046] It is believed that the present invention and many of its attendant advantages will be understood by the foregoing description of embodiments of the present invention, and it will be apparent that various changes may be made in the form, construction, and arrangement of the components thereof without departing from the scope and spirit of the invention or without sacrificing all of its material advantages. The form herein before described being merely an explanatory embodiment thereof, it is the intention of the following claims to encompass and include such changes.

CLAIMS

What is claimed is:

Claim 1. A system for measuring edge strain in a wafer production process comprising:

- a processor;

- a wafer illuminating system comprising:

- an incident light source configured to illuminate a portion of a wafer; and

- a pump light source configured to modulate a portion of light from the incident light source reflected off the portion of the wafer;

- a spectrograph configured to receive a reflected beam from the wafer illumination system via the wafer; and

- a light detector connected to the processor and configured for receiving light from the spectrograph,

wherein:

- the wafer illumination system is configured to illuminate an edge of a wafer; and

- the processor is configured to determine a strain value based on data received from the light detector.

Claim 2. The system of Claim 1, wherein:

- the wafer illumination system is configured to traverse a path such that an axis defined by the wafer illumination system and the portion of the wafer being illuminated is orthogonal to a tangent of the edge of the wafer over the entire path; and

- the processor is configured to control a position and orientation of the wafer illumination system along the path.

Claim 3. The system of Claim 1, wherein the processor is configured to correlate the strain value to one or more wafer production parameters.

Claim 4. The system of Claim 3, wherein the processor is configured to:
identify a wafer defect; and
correlate the strain value to the identified wafer defect and the one or more wafer production parameters.

Claim 5. The system of Claim 1, wherein the processor is configured to correlate the strain value to an anticipated wafer defect.

Claim 6. The system of Claim 1, wherein the processor is configured to compare the strain value to a threshold wafer strain value.

Claim 7. The system of Claim 1, wherein the processor is configured to:
identify a wafer defect; and
correlate the strain value to the identified wafer defect.

Claim 8. The system of Claim 1, wherein at least one of the incident light source or the pump light source is a laser.

Claim 9. A computer apparatus comprising:
a processor;
a light detector connected to the processor configured for detecting spectrographic data; and
memory connected to the processor for storing computer executable code, wherein the computer executable code is configured to instruct the processor to:

receive spectrographic data corresponding to a portion of a wafer edge; and
determine a strain value based on the spectrographic data.

Claim 10. The computer apparatus of Claim 9, wherein the computer executable code is configured to instruct the processor to orient a wafer illumination system to illuminate the portion of the wafer edge.

Claim 11. The computer apparatus of Claim 9, wherein the computer executable code is configured to instruct the processor to correlate the strain value to one or more wafer production parameters.

Claim 12. The computer apparatus of Claim 11, wherein the computer executable code is configured to instruct the processor to:
identify a wafer defect; and
correlate the strain value to the identified wafer defect and the one or more wafer production parameters.

Claim 13. The computer apparatus of Claim 9, wherein the computer executable code is configured to instruct the processor to correlate the strain value to an anticipated wafer defect.

Claim 14. The computer apparatus of Claim 9, wherein the computer executable code is configured to instruct the processor to compare the strain value to a threshold wafer strain value.

Claim 15. The computer apparatus of Claim 9, wherein the computer executable code is configured to instruct the processor to:
identify a wafer defect; and
correlate the strain value to the identified wafer defect.

Claim 16. A method for measuring strain at a wafer edge in a wafer production process comprising:

- producing, with a wafer inspection apparatus, an edge profile of a wafer in a wafer production process;
- illuminating, with a wafer illumination apparatus, an edge of the wafer;
- receiving, with a processor, spectrographic data corresponding to the edge of the wafer;
- determining, with the processor, a strain value based on the spectrographic data; and
- modifying a feature of the wafer production process based on the strain value.

Claim 17. The method of Claim 16, further comprising correlating the strain value to one or more wafer production parameters.

Claim 18. The method of Claim 17, further comprising

- identifying a wafer defect; and
- correlating the strain value to the identified wafer defect and the one or more wafer production parameters.

Claim 19. The method of Claim 16, further comprising correlating the strain value to an anticipated wafer defect.

Claim 20. The method of Claim 16, further comprising comparing the strain value to a threshold wafer strain value.

Claim 21. The method of Claim 16, further comprising identifying a portion of the edge profile to be excluded from illumination.

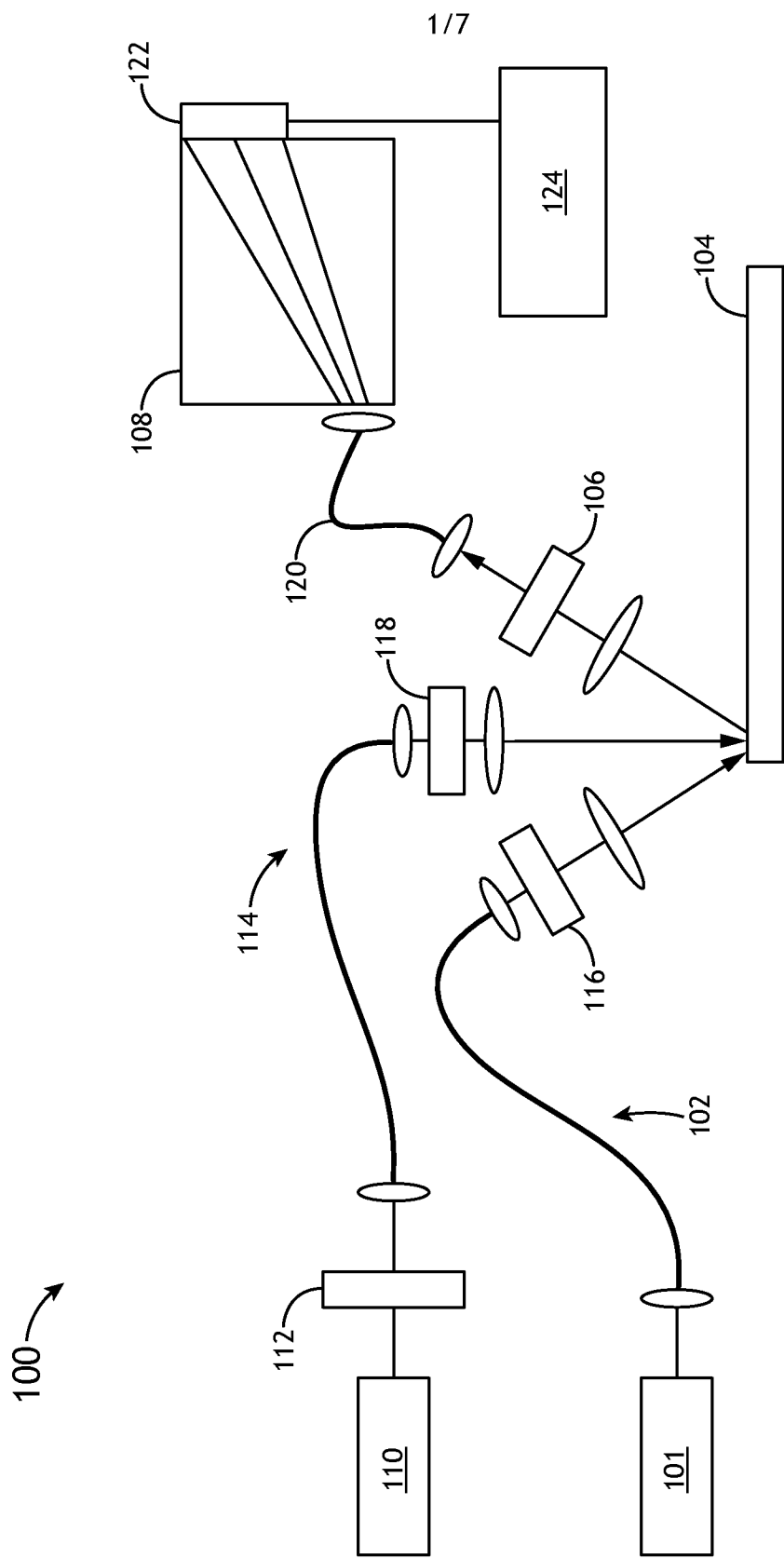


FIG.1

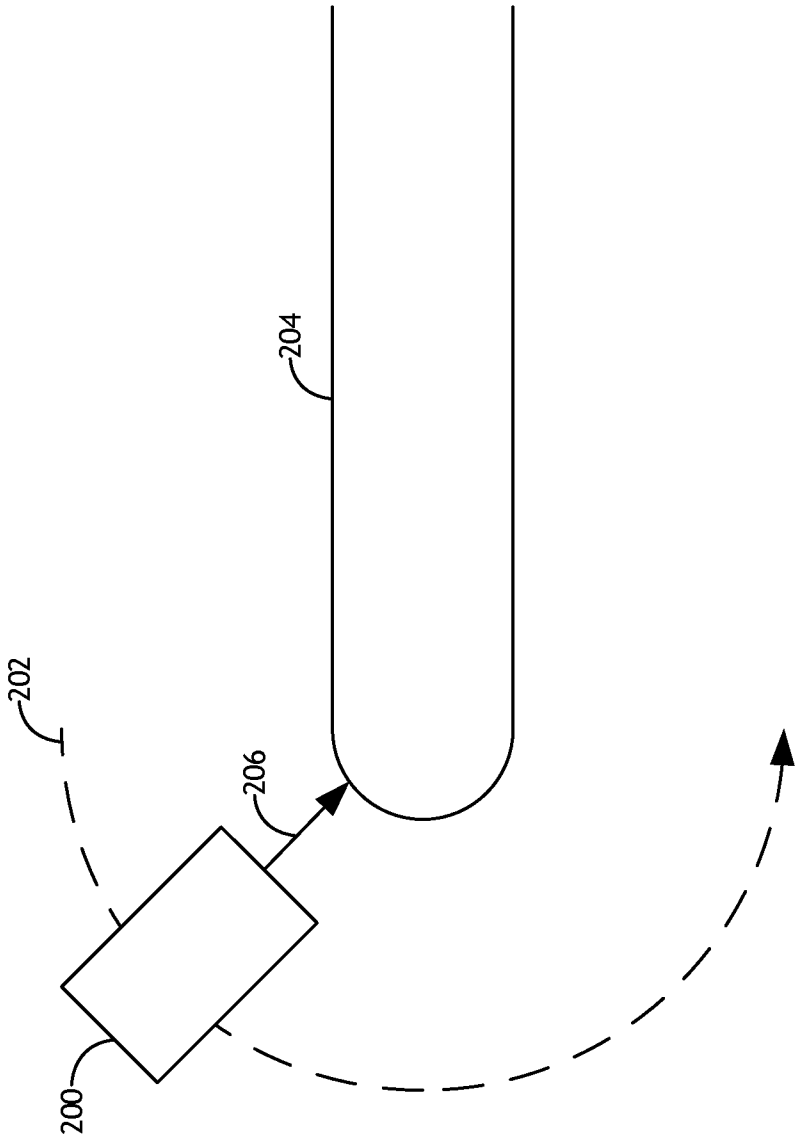


FIG. 2

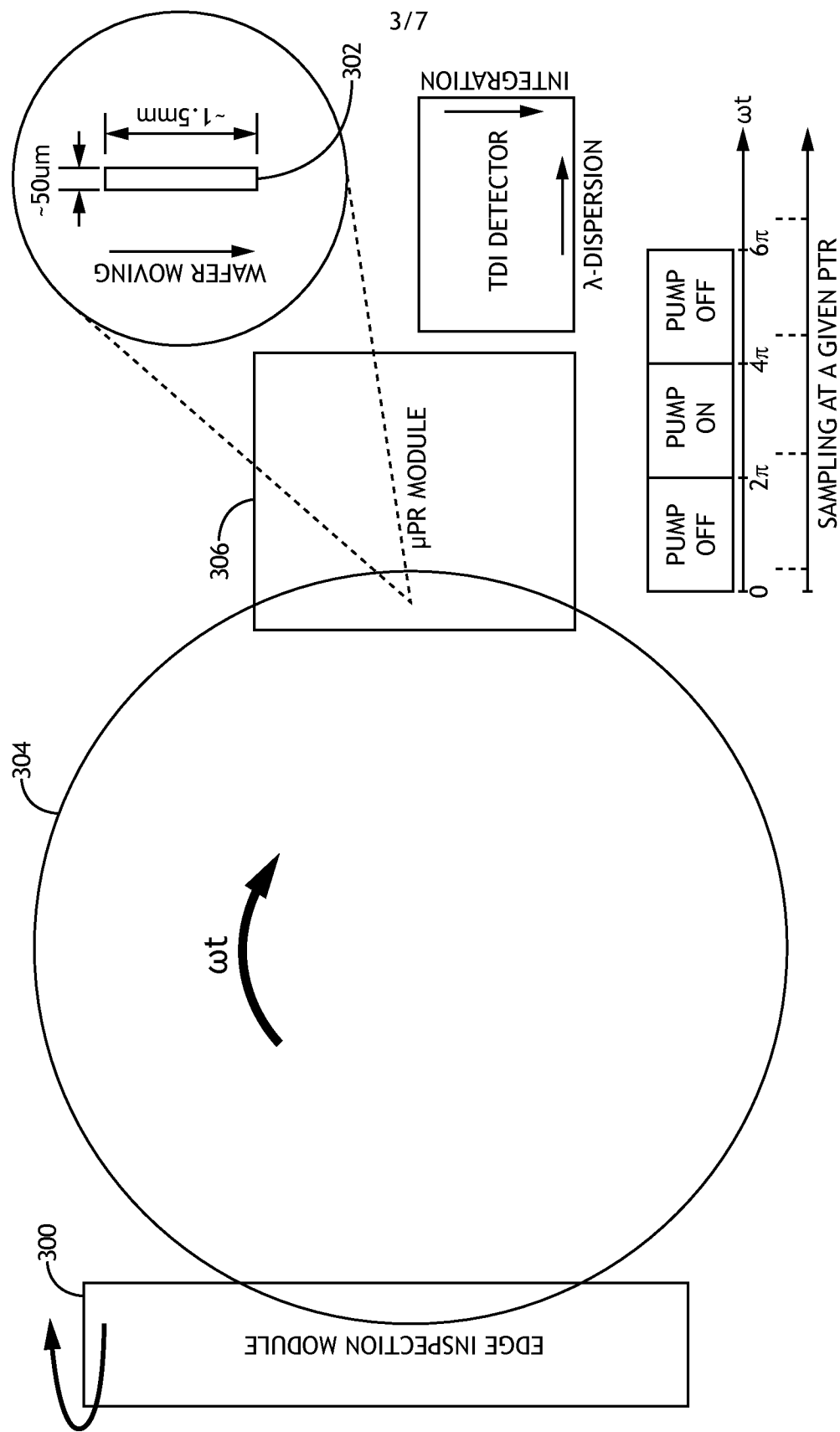


FIG.3

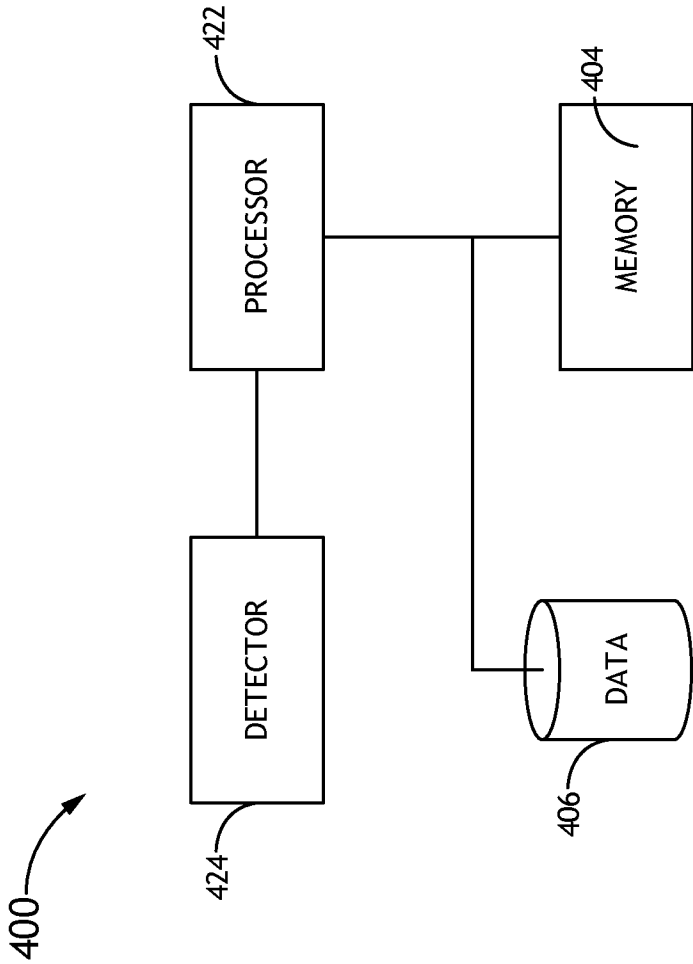


FIG.4

5/7

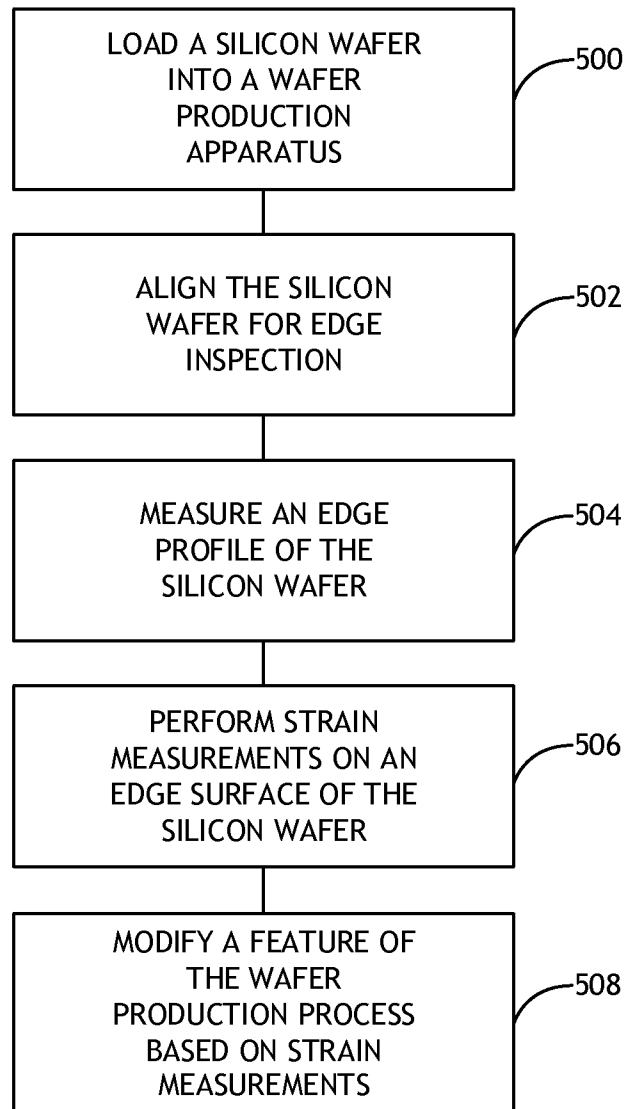


FIG.5

6/7

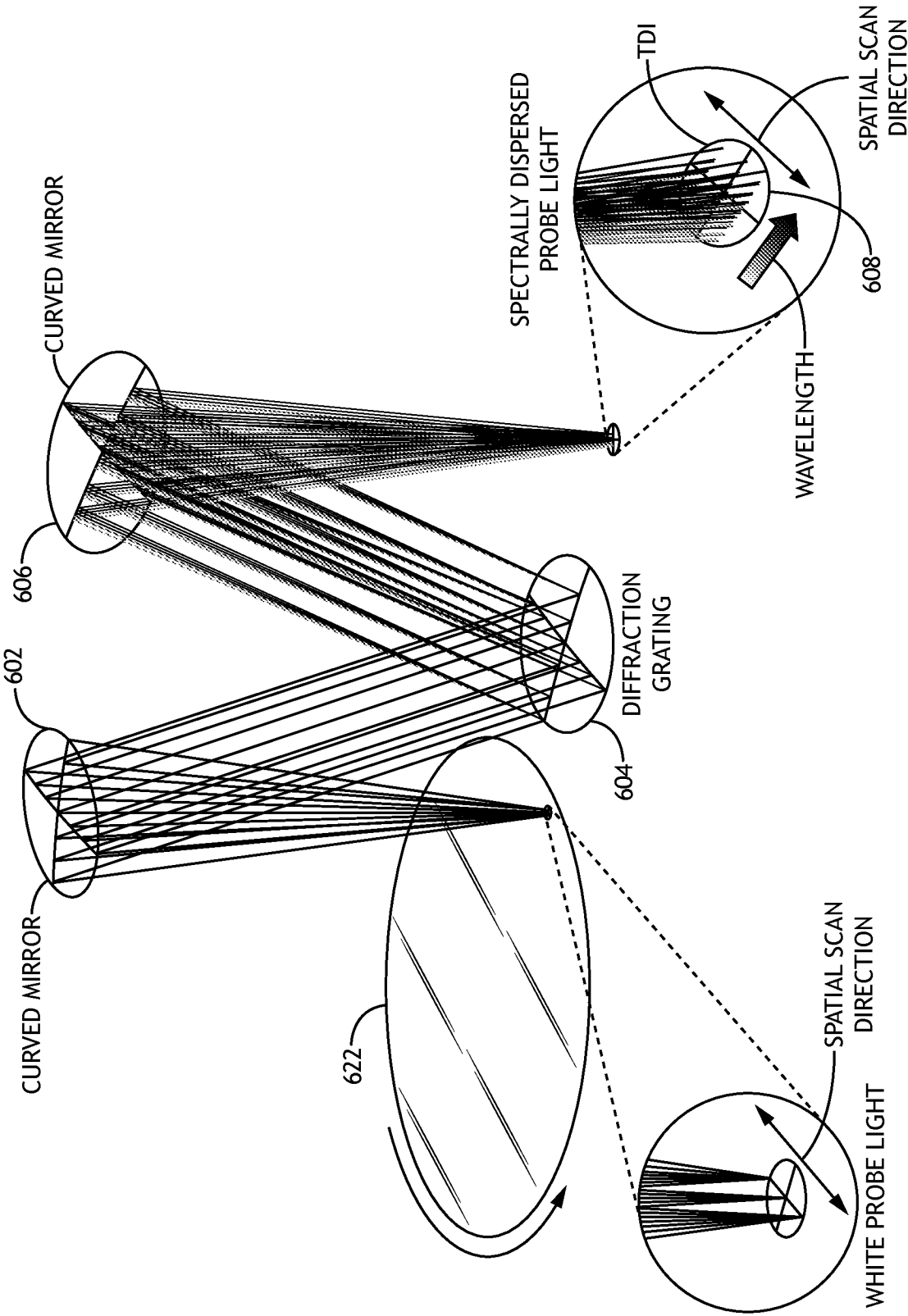
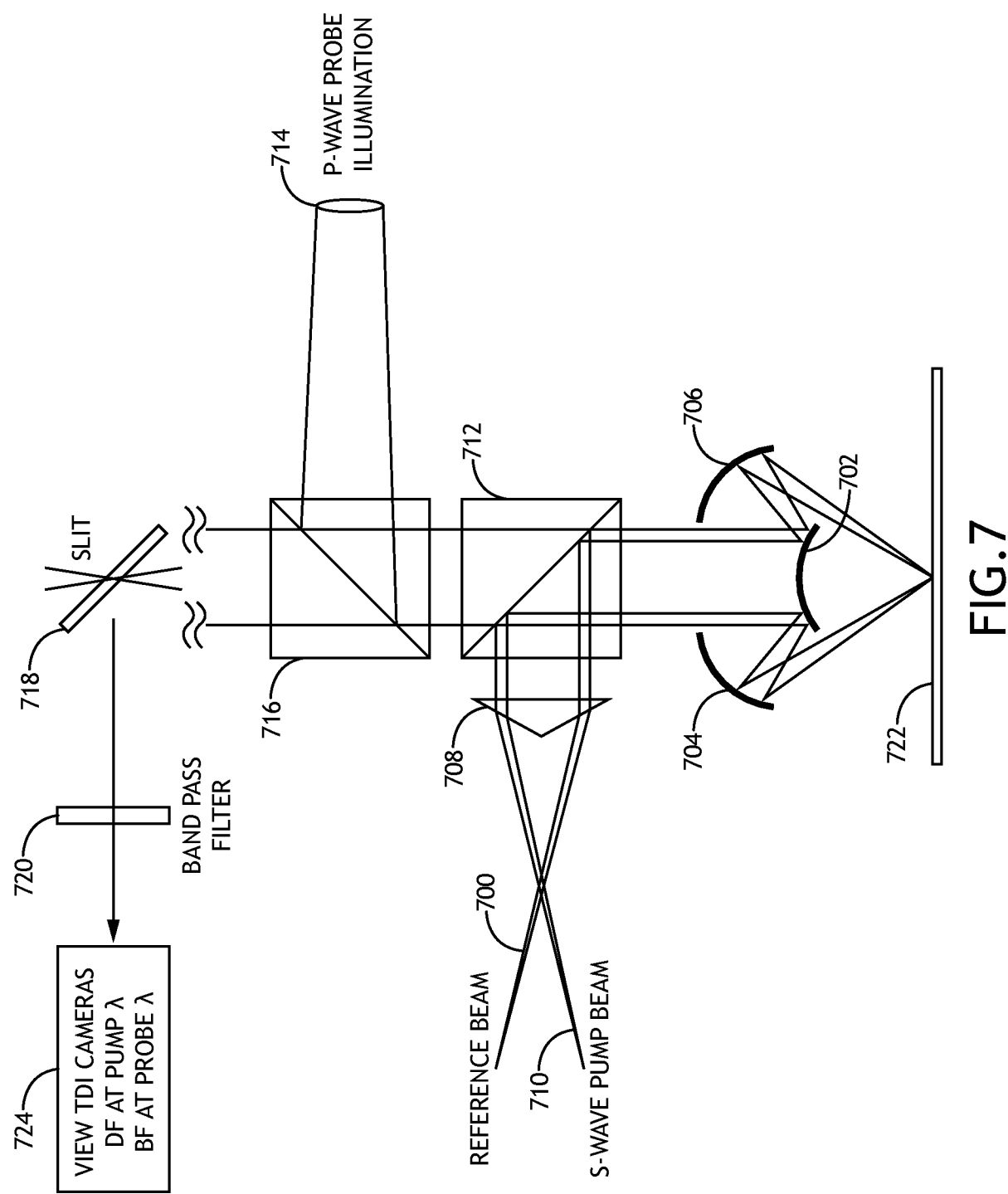


FIG.6



INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2015/026775**A. CLASSIFICATION OF SUBJECT MATTER****G01B 11/16(2006.01)i, G01N 21/95(2006.01)i, H01L 21/66(2006.01)i**

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

G01B 11/16; G01R 31/26; G01N 21/25; H04N 7/18; G06K 9/00; G01N 21/00; G01N 21/956; H01L 21/66

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Korean utility models and applications for utility models

Japanese utility models and applications for utility models

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

eKOMPASS(KIPO internal) & Keywords: wafer edge, strain, defect, photorefectance spectroscopy, illuminating system, spectrograph and detector**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 2009-0033931 A1 (MURTAGH et al.) 05 February 2009 See abstract, paragraphs [0068]-[0090], [0173], [0175], claims 1, 9, 24 and figures 1, 2.	1-21
Y	US 2012-0007978 A1 (PASSEK et al.) 12 January 2012 See abstract, paragraphs [0018]-[0030], [0045]-[0069], claims 1, 2, 12 and figure 1.	1-21
A	US 7755752 B1 (SALNIK et al.) 13 July 2010 See abstract, column 3, lines 26-39, column 7, line 47 - column 8, line 7, column 8, lines 30-60 and figures 3, 4.	1-21
A	WO 2004-072629 A1 (NANYANG TECHNOLOGICAL UNIVERSITY et al.) 26 August 2004 See abstract, page 11, lines 1-18, claim 10 and figure 4.	1-21
A	US 2003-0098704 A1 (DU-NOUR et al.) 29 May 2003 See abstract, claim 1 and figures 3, 10.	1-21



Further documents are listed in the continuation of Box C.



See patent family annex.

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"&" document member of the same patent family

Date of the actual completion of the international search

26 August 2015 (26.08.2015)

Date of mailing of the international search report

26 August 2015 (26.08.2015)

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

PCT/US2015/026775

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