



US009546946B2

(12) **United States Patent**
Golovanevsky et al.

(10) **Patent No.:** **US 9,546,946 B2**

(45) **Date of Patent:** **Jan. 17, 2017**

(54) **METROLOGY TARGET IDENTIFICATION, DESIGN AND VERIFICATION**

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(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 162 days.

(21) Appl. No.: **14/361,610**

(22) PCT Filed: **Mar. 28, 2014**

(86) PCT No.: **PCT/US2014/032248**

§ 371 (c)(1),

(2) Date: **May 29, 2014**

(87) PCT Pub. No.: **WO2014/160976**

PCT Pub. Date: **Oct. 2, 2014**

(65) **Prior Publication Data**

US 2015/0233814 A1 Aug. 20, 2015

Related U.S. Application Data

(60) Provisional application No. 61/806,053, filed on Mar. 28, 2013.

(51) **Int. Cl.**

A61F 11/06 (2006.01)

G10K 11/16 (2006.01)

H03B 29/00 (2006.01)

G01N 21/01 (2006.01)

G01N 21/95 (2006.01)

(52) **U.S. Cl.**

CPC **G01N 21/01** (2013.01); **G01N 21/9501** (2013.01); **G01N 2201/025** (2013.01)

(58) **Field of Classification Search**

CPC G10N 21/01; G10N 21/9501; G10N 2201/025

USPC 381/71.2; 356/244
See application file for complete search history.

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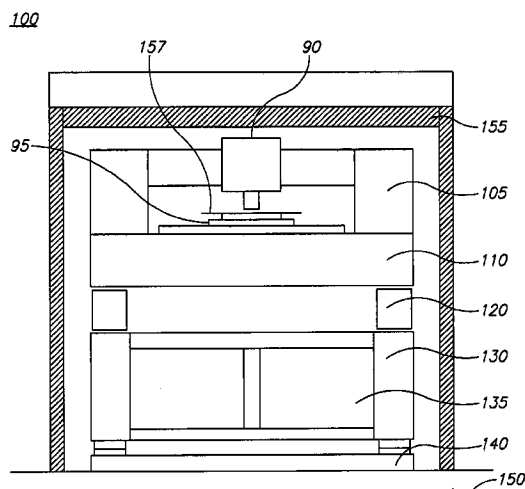
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(57) **ABSTRACT**

Metrology tools are provided, which comprise both active and passive vibration isolation devices, passive or active isolation systems such as constrained layer dampers, particle impact dampers or liquid impact dampers, and/or noise cancellation transducers, combined in different supporting structures of the metrology tool to dampen and reduce vibrations at a wide range of frequencies and intensities, and to which frequency range spectral analysis and optimization may be applied to determine specific tool configurations according to the provided principles.

16 Claims, 7 Drawing Sheets



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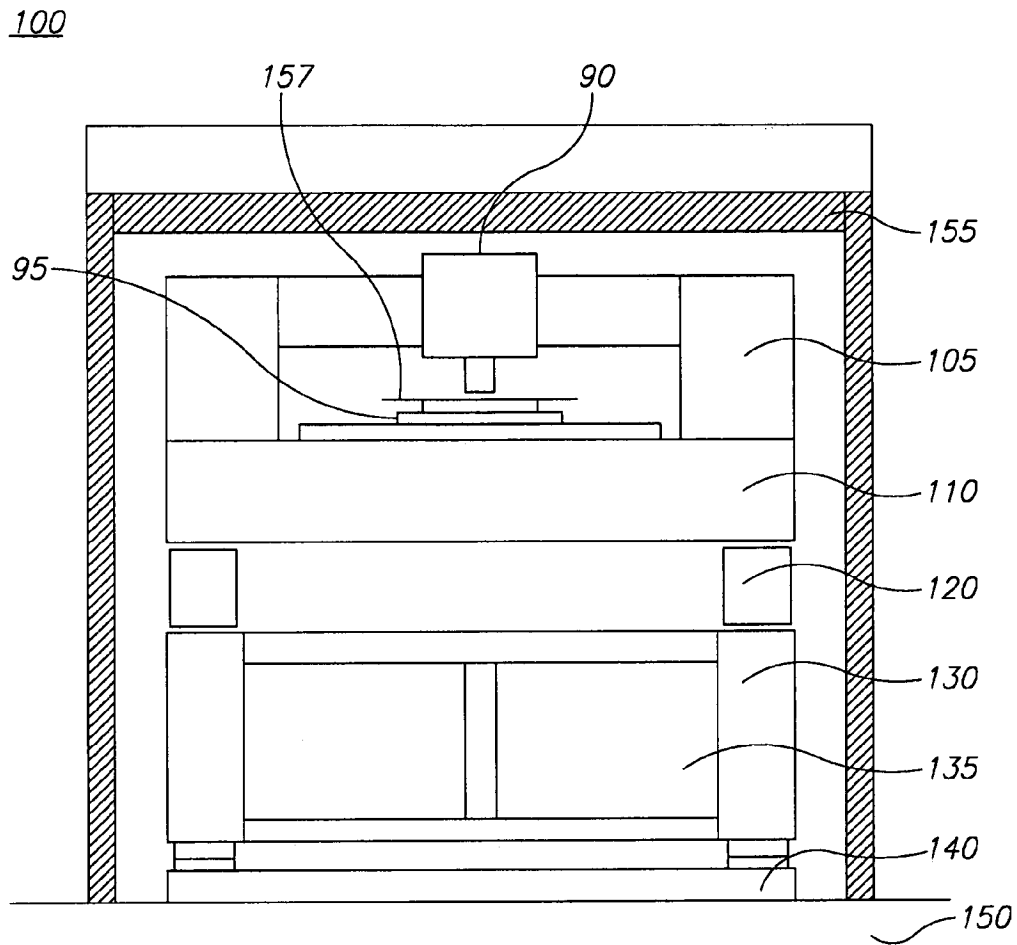


Figure 1

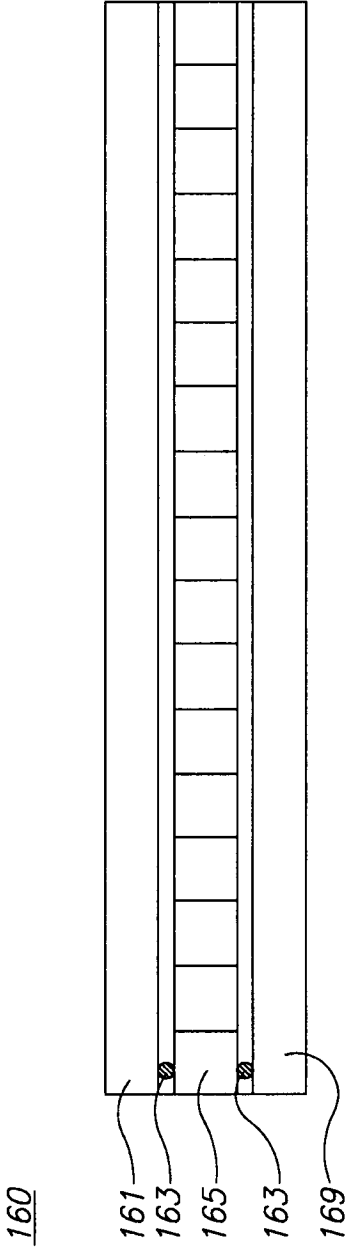


Figure 2A

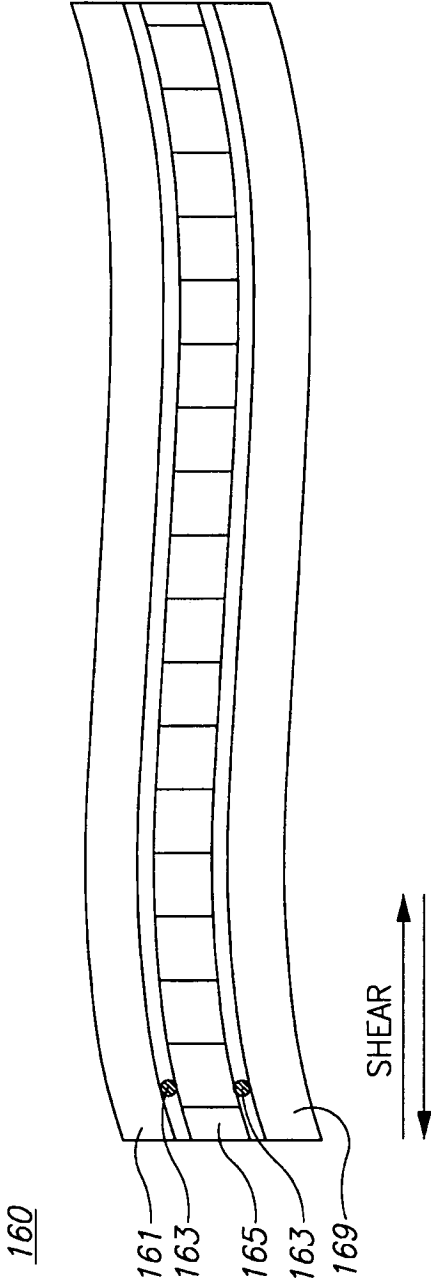


Figure 2B

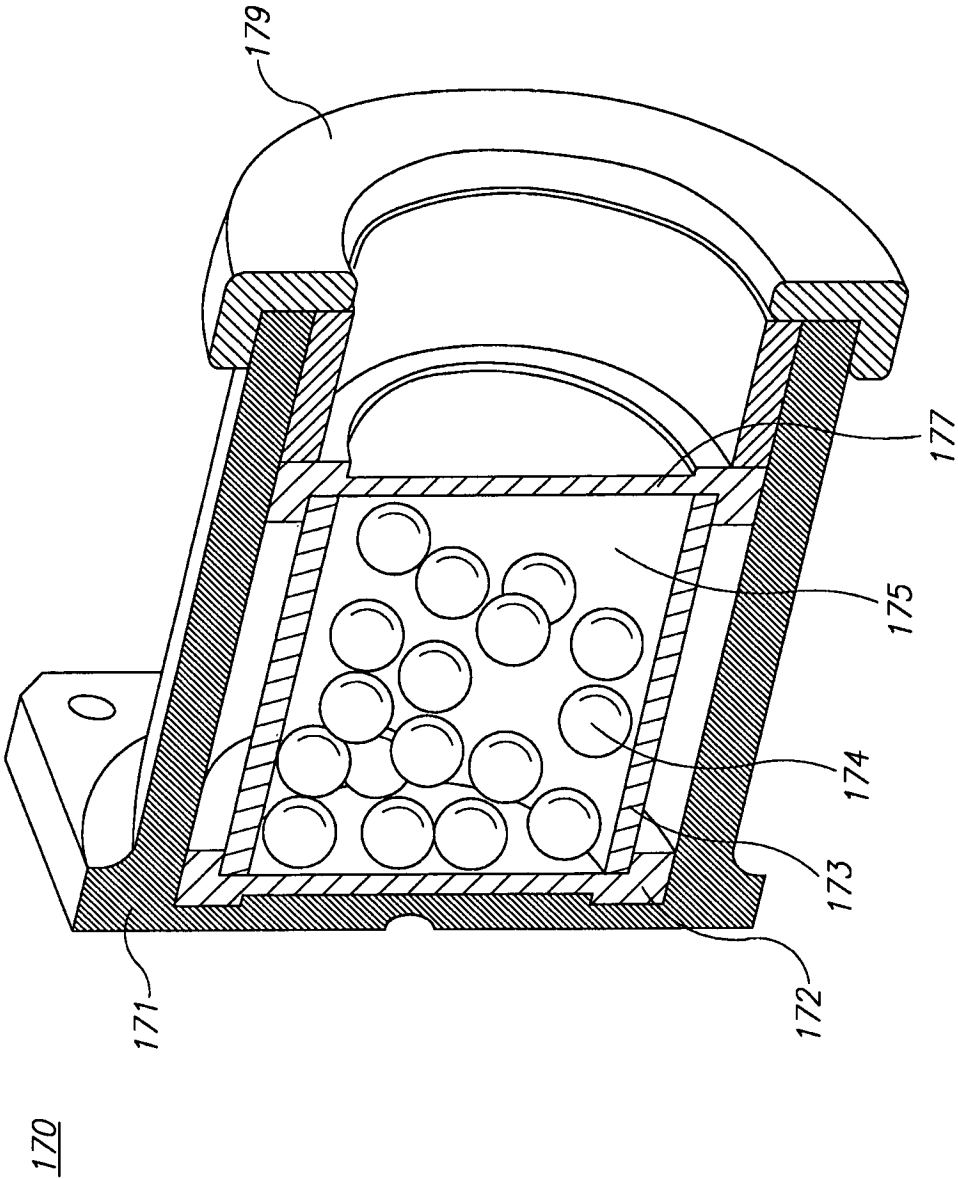


Figure 3

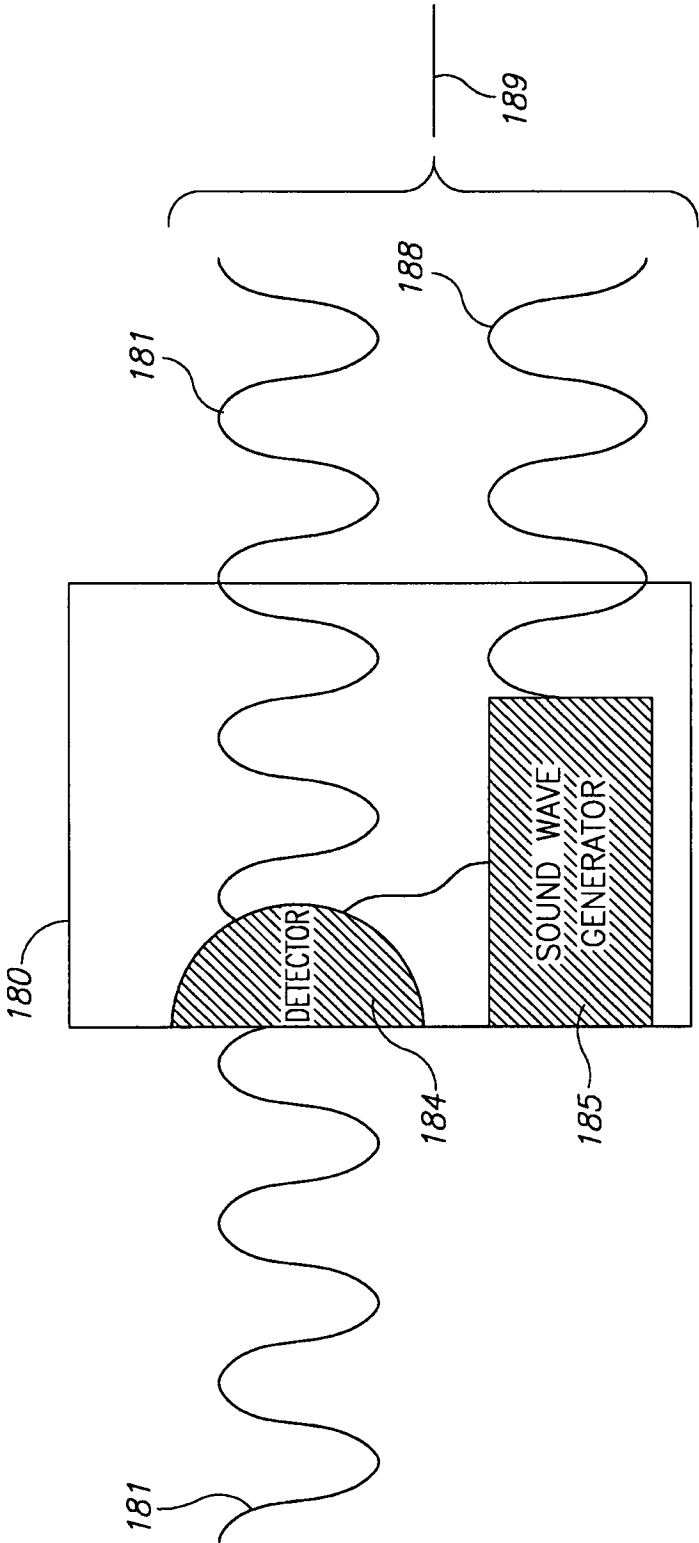


Figure 4

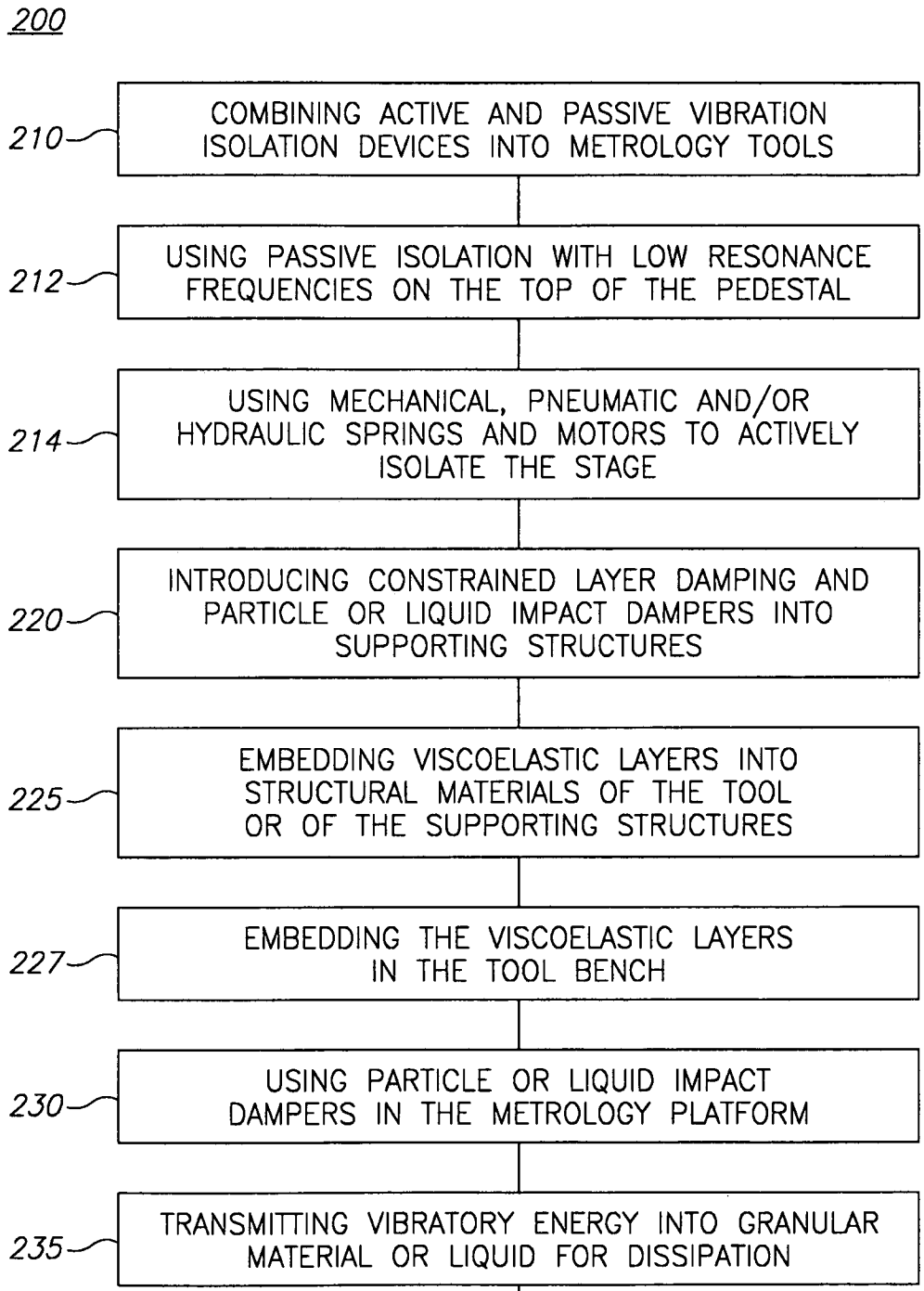


Figure 5

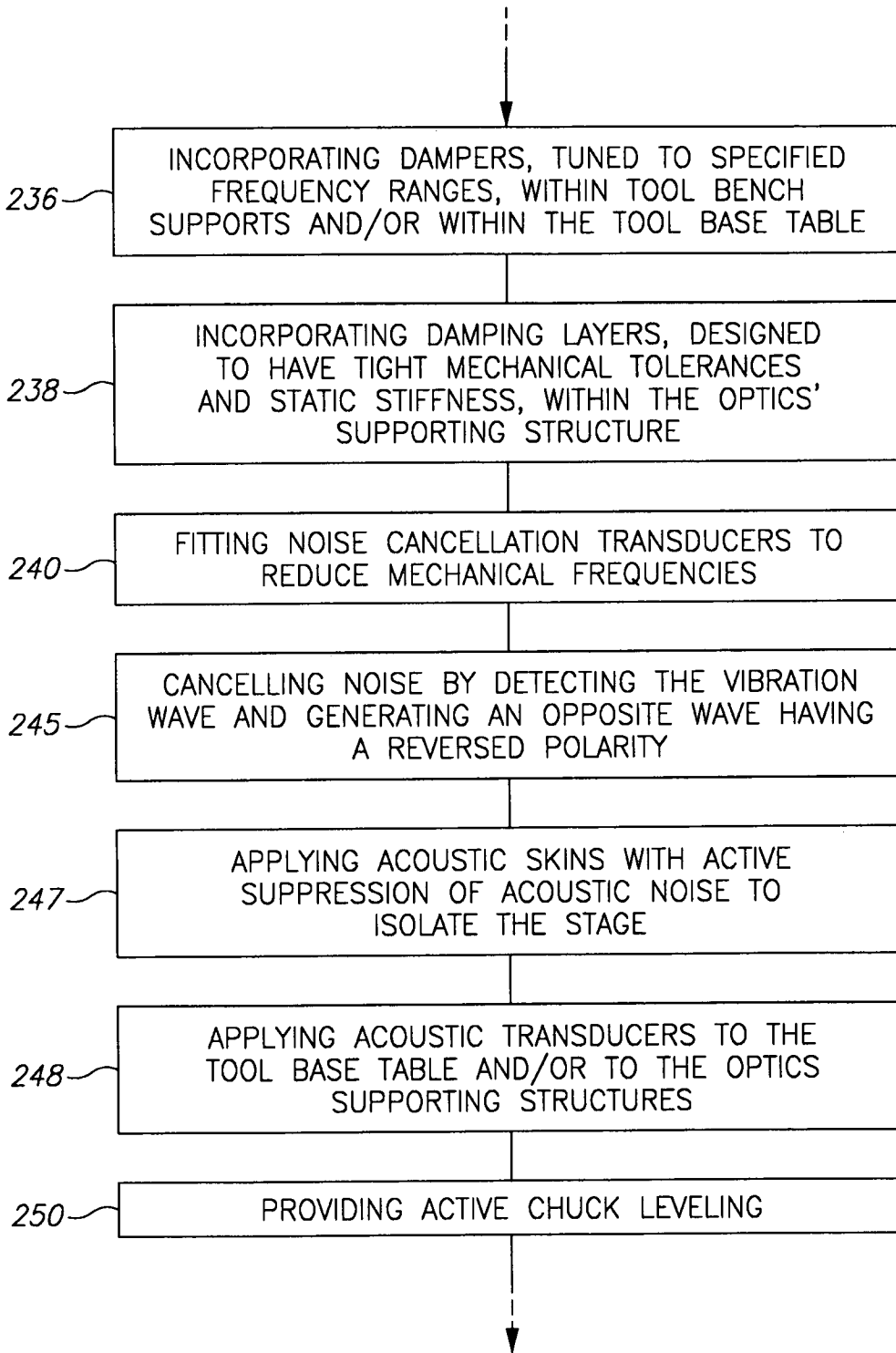


Figure 5 (cont. 1)

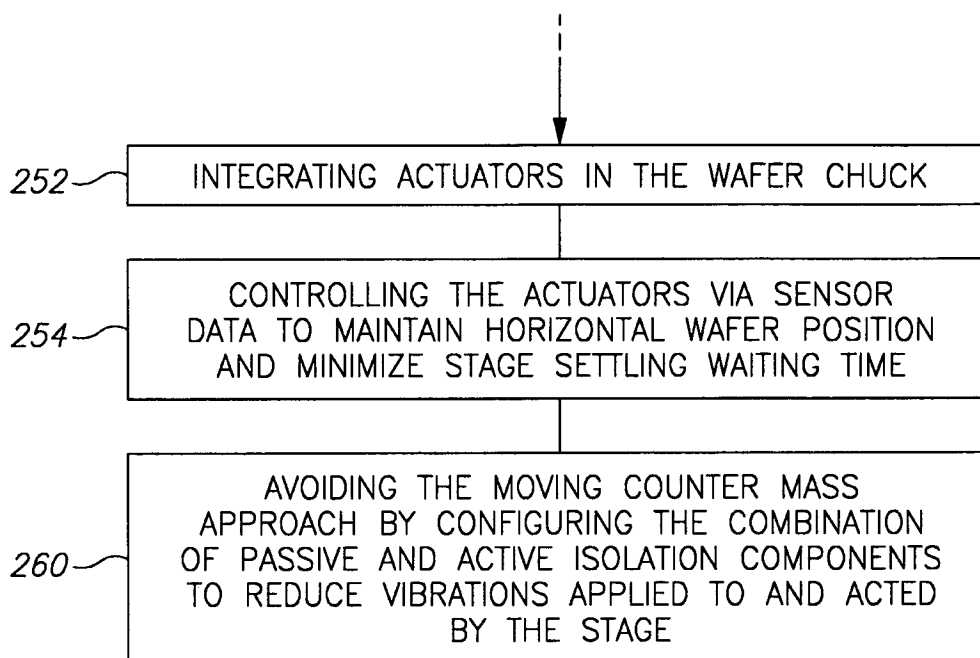


Figure 5 (cont. 2)

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**METROLOGY TARGET IDENTIFICATION,
DESIGN AND VERIFICATION**CROSS-REFERENCE TO RELATED
APPLICATIONS

This application is a Continuation of International Patent Application Serial No. PCT/US2014/32248, filed on Mar. 28, 2014, which application claims priority of U.S. Provisional Patent Application No. 61/806,053, filed on Mar. 28, 2013, which applications are incorporated herein by reference.

FIELD OF THE INVENTION

The present invention relates to the field of vibration damping systems, and more particularly, to vibration damping in metrology tools.

BACKGROUND OF THE INVENTION

U.S. Pat. No. 7,502,103, incorporated herein by reference in its entirety, teaches dampening stage vibrations by implementing a moving counter mass approach. With advancing metrology technology, this approach becomes less cost effective and requires increasing space to accommodate the moving masses.

BRIEF SUMMARY OF THE INVENTION

One aspect of the present invention provides a metrology tool comprising both active and passive vibration isolation devices.

An additional aspect of the present invention provides a method comprising combining at least one active vibration isolation device and at least one passive vibration isolation device into a metrology tool.

These, additional, and/or other aspects and/or advantages of the present invention are set forth in the detailed description which follows; possibly inferable from the detailed description; and/or learnable by practice of the present invention.

BRIEF DESCRIPTION OF THE DRAWINGS

For a better understanding of embodiments of the invention and to show how the same may be carried into effect, reference will now be made, purely by way of example, to the accompanying drawings in which like numerals designate corresponding elements or sections throughout.

In the accompanying drawings:

FIG. 1 is a high level schematic illustration of a metrology tool layout, according to some embodiments of the invention;

FIG. 2A is a high level schematic illustration of a constrained-layer damping system, according to some embodiments of the invention;

FIG. 2B is a high level schematic illustration of a constrained-layer damping system, according to some embodiments of the invention;

FIG. 3 is a high level schematic illustration of a particle damper, according to some embodiments of the invention;

FIG. 4 is a high level schematic illustration of the principle of operation of a noise cancellation transducer, according to some embodiments of the invention; and,

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FIG. 5 is a high level flowchart illustrating a method, according to some embodiments of the invention.

DETAILED DESCRIPTION OF THE
INVENTION

With specific reference now to the drawings in detail, it is stressed that the particulars shown are by way of example and for purposes of illustrative discussion of the preferred embodiments of the present invention only, and are presented in the cause of providing what is believed to be the most useful and readily understood description of the principles and conceptual aspects of the invention. In this regard, no attempt is made to show structural details of the invention in more detail than is necessary for a fundamental understanding of the invention, the description taken with the drawings making apparent to those skilled in the art how the several forms of the invention may be embodied in practice.

Before at least one embodiment of the invention is explained in detail, it is to be understood that the invention is not limited in its application to the details of construction and the arrangement of the components set forth in the following description or illustrated in the drawings. The invention is applicable to other embodiments or of being practiced or carried out in various ways. Also, it is to be understood that the phraseology and terminology employed herein is for the purpose of description and should not be regarded as limiting.

Metrology tools are provided, which comprise both active and passive vibration isolation devices. Metrology tools may comprise passive isolation system such as constrained layer dampers, particle impact dampers or liquid impact dampers, and/or noise cancellation transducers, combined in different supporting structures of the metrology tool to dampen and reduce vibrations at a wide range of frequencies and intensities. Frequency range spectral analysis and optimization may be applied to determine specific tool configurations according to the provided principles.

The presented tools and methods isolate the tools from the surrounding noise and/or vibrations and reduce the impact of the tools on their surroundings. The isolation system may be designed and optimized to isolate the more sensitive equipment like the scanner from the metrology tool while keeping the metrology tool isolated from environment. The present invention discloses optimized combinations of active and passive vibration damping mechanisms which are designed to face the challenge of the increasing moving masses in metrology tools in a cost effective way. A number of different technologies are tailored according to respective frequency ranges with respect to specific applications. Certain embodiments of the present invention provide isolation solutions for metrology tools which both isolate the metrology system from the environment and isolate the environment from the metrology systems. The solutions provide vibration isolation and vibrational energy dissipation in a cost effective and scalable manner.

FIG. 1 is a high level schematic illustration of a metrology tool layout **100**, according to some embodiments of the invention. Tool **100** comprises optics **90**, stage **95**, wafer chuck **157**, optics-supporting structure **105**, a tool base table **110** (e.g., an optics bench including chuck and wafer stage), an isolation system **120**, a tool bench **135**, tool bench supports **130** and a pedestal **140** (or floor **150**).

While present metrology tools generally use active or passive isolation systems **120**, metrology tool **100** combines both active and passive isolation systems **120** as well a

passive isolation elements in tool bench supports **130** and in pedestal **140** (or in floor **150**).

FIGS. **2A** and **2B** are high level schematic illustrations of a constrained-layer damping system **160**, according to some embodiments of the invention. System **160** comprises a damping layer **165** attached (e.g., by adhesive **163**) to constraining layers **161**, **169**. FIG. **2A** schematically illustrates system **160** in rest, without applied forces, while FIG. **2B** schematically illustrates system **160** under application of horizontal shear forces. Damping layer **165** operates to mild the effect of the shear forces on containing layers **161**, **169**. Energy is dissipated as a result of shear deformation of damping layer **165** and the resulting extension and compression of the material under flexural stress applied by basal constraining layer **169**.

Constrained layer damping means **160** may comprise embedded viscoelastic layer(s) **165** in a structural material. Shear deformation of viscoelastic layer **165** provides energy dissipation and effective damping for natural frequency of the supporting structure.

FIG. **3** is a high level schematic illustration of a particle damper **170**, according to some embodiments of the invention. Particle damper **170** comprises particles **174** within an enclosure **175** that is constrained by walls **173**, base **172** and cover **177**, which are enclosed within housing **171** supporting base **172** and walls **173** and a cap **179** covering housing **171** and configured to transmit applied forces onto cover **177**. Vibratory energy in particle damper **170**, originating e.g., from the stage movement as part of optics-supporting structure **105**, or vibrations from floor **150**, is transmitted into granular material **174** and dissipated within it. Without being bound by theory, particle impact dampers **170** dissipate energy through the friction caused by motion of particles **174** within the enclosure defined by walls **173**, base **172** and cover **177** and deformation of particles **174** themselves. Some of the volume inside the metrology platform supporting structure **105** or other parts of tool **100** may be partially filled with particles **174** such as sand, ceramics, plastic or metal beads, or any mixture/combination of them.

In certain embodiments, granular material **174** may be replaced by a viscous liquid to provide a liquid-based particle damper **170**. Particle damper **170** is a cost effective way to dissipate energy over a broad range of frequencies and temperatures. Particle damper **170** provides damping of stage created shocks and high-g load absorption. Particle damper **170** may be designed to suppress (dampen) the natural frequencies of isolation system **120**, structure **105** and/or tool **100** or parts thereof (similarly to the action of a Tuned Mass Damper, TMD). Particle damper **170** may be designed to suppress (dampen) several natural frequencies existing in tool **100** (and thus act like a number of TMDs).

Passive isolation system **120** may be configured to comprise shear layer constrained-layer damping elements **160** (FIG. **2**) or/and particle damper **170** or viscous-liquid dampers (FIG. **3**). Any supporting structure like optic-supporting structure **105**, tool base table **110**, tool bench **135**, tool legs **130** and levelers and pedestal **140** may comprise shear layer damping elements **160** and or particle damper **170** or viscous-liquid dampers embedded in respective specially designed cavities.

Tool **100** may comprise a combination of passive isolation system **120** such as constrained layer damping **160** in supporting structure **105**, and particle dampers (or liquid impact dampers) **170** in supporting structure **105** and/or in tool bench **135**, tool legs **130** or pedestal **140** (or floor **150**).

Such combination provides vibrational damping in a wide dynamic range and good transmissibility for vibration isolation system.

Particle damper **170** or liquid impact dampers may be arranged to absorb or dissipate a part of the stage impact energy to reduce the energy that has to be handled by passive isolation system **120** (comprising e.g., constrained-layer damping elements **160**) and/or the energy transferred to the environment.

FIG. **4** is a high level schematic illustration of the principle of operation of a noise cancellation transducer **180**, according to some embodiments of the invention. Tool **100** may further comprise noise cancellation transducers **180** to reduce an even larger range of mechanical frequencies. Noise cancellation transducers **180** effectively cancel mechanical noise of any origin (e.g., air, floor, structure) if it resides in their spectral response range.

Noise cancellation transducers **180** are configured to detect (via a detector **184**) an input sound wave **181** (noise, vibrations or other) and generate (via a generator **185**) an identical sound wave with reversed polarity **188** (having a negative sign, anti-phase, 180° phase difference). Vibration or noise sound wave **181** and induced (device generated) sound wave **188** interfere and cancel each other resulting in a zero (or very close to zero) vibration/noise/sound wave **189**. This technique is limited to the frequency and amplitude response of both detection device **184** and inducer **185** of the negative sound wave device. Multiple transducers **180** may be deployed in synchronization to generate broader frequency response (e.g., the interference pattern from multiple sources may be used to generate a more elaborate cancellation pattern). It is noted that sound waves **181** and **189** are depicted in FIG. **4** as pure sine wave for simplicity and illustration purposes only, and in a non-limiting manner, as usually more complicated inputs **181** and cancellation waves **189** are expected). Advantageously, noise cancellation transducers **180** widen the dynamic range and improve the transmissibility for vibration isolation system.

In a non-limiting example, the following aspects may be taken into consideration. Any of these aspects may be combined or adapted to specific conditions.

Passive isolation with low resonance frequency may be associated with or provided on top of, beneath or within pedestal **140**, to reduce impact of tool **100** on the environment and isolate tool **100** from environment. For example, the working frequency range of pedestal passive isolation may be chosen to be within the range of 0.5 Hz to 100 Hz or 150 Hz. For example, the passive isolation may be based isolation based on a negative stiffness effect.

Tool bench **135** is configured to be stiff and massive, with relatively loose mechanical tolerances. Viscoelastic layers (e.g., shear layer constrained-layer damping elements **160**) may be embedded into tool bench **135** to dampen relatively high frequencies, for example within a range from 50 Hz up to 1 KHz. The mass of tool bench **135** may be configured to act as low pass filter.

One or more of particle damper **170** (particle-based or liquid-based) may be designed to be set within the internal space of tool bench supports ("legs") **130**, in place of or in combination with tuned mass damper(s), TMD). Specifically, the embedded impact damper **170** and/or TMDs may be tuned with respect to a few specific resonant frequencies that should be effectively dampened. In certain embodiments, particle damper **170** may be configured to dampen vibrations within a specified frequency range and additional TMDs may be tuned to certain specific frequencies within or

outside the specified frequency range. The specified frequency range may be relative high and may extend up to a few kHz (e.g., 1-10 kHz).

Isolation system **120** may be designed as an active isolation system to comprise mechanical, pneumatic and/or hydraulic springs and motors to reduce the impact of stage **95** on tool **100** and its environment, as well as to isolate stage **95** and tool **100** from the environment. Hence, isolation system **120** may be designed to handle vibrations from any or both stage **95** and floor **150**. Active isolation system **120** may be configured to handle vibration frequencies with a range between 2-3 Hz and 100-150 Hz.

Tool base table **110**, which is designed to be stiff and massive (made e.g., of granite), may comprise pockets in which a particle damper **170** (particle-based or liquid-based) and/or TMDs are incorporated. These may be configured to dampen vibration over specified frequency ranges and/or at specific resonant frequencies. The frequency ranges may be relatively high and may extend up to a few kHz (e.g., 1-10 kHz). The mass of tool base table **110** may be configured to act as low pass filter.

Optics supporting structure **105**, which is configured to be stiff and have tight mechanical tolerances, may incorporate structural damping elements such as damping layers and/or shear layer constrained-layer damping elements **160** and/or structural damping devices like D-strut devices which are characterized by very tight mechanical tolerances and static stiffness.

Tool **100** may be further isolated from the environment, e.g., from acoustic vibrations, by acoustic skins **155** having acoustic pad isolation and active suppression of acoustic noise, using, for example, noise cancellation transducers **180**. Acoustic transducers such as noise cancellation transducers **180** may be located on skins **155**, tool frame, tool base table **110**, tool bench **135** or on supporting structures such as tool bench support **130** and optics supporting structure **105**.

Tool stage **95** may comprise one assembly for all axes (X, Y, Z, T) or comprise a distributed system with separate optic moving axes and wafer moving axes. Wafer chuck **157** may comprise with integrated vertical actuators (actuators may comprise, e.g., voice coil, different types of piezo motors, etc.) for active chuck leveling control during the measurements, especially during stage settling time. Chuck subsystem **157** may comprise actuators to control Z/tip/tilt and sensors like gyro and accelerometers to provide the required input. In addition, stage feed forward signal is required and incorporated into the actuators' control system. The sensors may be installed on the system element that defines the optical axis (e.g., the main objective) in order to insure perpendicularity between wafer chuck **157** and the optical axis of the measurement head. The actuators may be controlled to maintain or control horizontal wafer position (or the perpendicularity between wafer and optical axis) during all measurement process and thus reduce the MAM (Move—Acquire—Measure) by minimizing waiting time during the settling stage of **95**.

Advantageously, while documents such as U.S. Pat. No. 7,502,103 teach dampening stage vibrations by implementing a moving counter mass approach, the present invention does not require using additional moving masses to balance out stage movements.

Hence, the present invention provides a simpler and more reliable solution which is more cost-effective and is less spacious. The disclosed comprehensive hybrid vibration isolation system, having active and/or passive components, provides cost effective, space-effective metrology tool iso-

lation system, by combining and implementing a number of different techniques in the appropriate locations in tool **100**. Specific configurations may be adapted to requirements with respect to the analysis of the distribution of vibration frequencies throughout tool **100** and its environment, which was presented above.

FIG. **5** is a high level flowchart illustrating a method **200**, according to some embodiments of the invention. Method **200** may comprise stages for producing, preparing and/or using metrology tool **100**, such as any of the following stages, irrespective of their order.

Method **200** comprises combining active and passive vibration isolation devices into metrology tools (stage **210**). Method **200** may comprise introducing constrained layer damping and particle or liquid impact dampers into the supporting structure (stage **220**) and/or embedding viscoelastic layers into structural materials of the tool or the supporting structures (stage **225**) and/or using of particle or liquid impact dampers in the metrology platform (stage **230**) to transmit vibratory energy into granular material or liquid for dissipation (stage **235**) and/or fitting noise cancellation transducers to reduce mechanical frequencies (stage **240**) by cancelling noise through detection the vibration wave and generation of an opposite wave having reversed polarity (stage **245**).

Method **200** may further comprise any of the following stages: Using passive isolation with low resonance frequencies on the top of the pedestal (stage **212**), using mechanical, pneumatic and/or hydraulic springs and motors to actively isolate the stage (stage **214**), embedded the viscoelastic layers in the tool bench (stage **227**), incorporating dampers, tuned to specified frequency ranges, within tool bench supports and/or within the tool base table (stage **236**), and incorporating damping layers, designed to have tight mechanical tolerances and static stiffness, within the optics' supporting structure (stage **238**).

Method **200** may further comprise applying acoustic skins with active suppression of acoustic noise to isolate the stage (stage **247**) and applying acoustic transducers to the tool base table and/or to the optics' supporting structures (stage **248**) as well as possibly to other supporting structures.

Method **200** may further comprise providing active chuck leveling (stage **250**), for example by integrating actuators in the wafer chuck (stage **252**) and/or controlling the actuators via sensor data to maintain horizontal wafer position and minimize stage settling waiting time (stage **254**).

Any configuration of the stages disclosed above may be adjusted to allow avoiding the moving counter mass approach by configuring the combination of passive and active isolation components to reduce vibrations applied to and acted by the stage (stage **260**).

Advantageously, disclosed tools **100** overcome the current limitations in damping vibrations near to natural frequencies of components of tool **100**, limitations in transmissibility function of isolation system, limitations in dynamic range, limitations in energy dissipation, as well as attenuating the transfer of most of the stage impact to the floor. The disclosed invention overcomes current challenges of limited dynamical ranges and low degree of energy dissipation of vibration damping elements in metrology tools, and furthermore of damping component natural frequencies and of insufficient transmissibility functions. Disclosed solutions handle the bidirectional transfer of vibrations—from the environment to the stage as well as from the stage to the environment, and thus provides a full and adjustable vibration damping solution.

In the above description, an embodiment is an example or implementation of the invention. The various appearances of “one embodiment”, “an embodiment”, “certain embodiments” or “some embodiments” do not necessarily all refer to the same embodiments.

Although various features of the invention may be described in the context of a single embodiment, the features may also be provided separately or in any suitable combination. Conversely, although the invention may be described herein in the context of separate embodiments for clarity, the invention may also be implemented in a single embodiment.

Certain embodiments of the invention may include features from different embodiments disclosed above, and certain embodiments may incorporate elements from other embodiments disclosed above. The disclosure of elements of the invention in the context of a specific embodiment is not to be taken as limiting their use in the specific embodiment alone.

Furthermore, it is to be understood that the invention can be carried out or practiced in various ways and that the invention can be implemented in certain embodiments other than the ones outlined in the description above.

The invention is not limited to those diagrams or to the corresponding descriptions. For example, flow need not move through each illustrated box or state, or in exactly the same order as illustrated and described.

Meanings of technical and scientific terms used herein are to be commonly understood as by one of ordinary skill in the art to which the invention belongs, unless otherwise defined.

While the invention has been described with respect to a limited number of embodiments, these should not be construed as limitations on the scope of the invention, but rather as exemplifications of some of the preferred embodiments. Other possible variations, modifications, and applications are also within the scope of the invention. Accordingly, the scope of the invention should not be limited by what has thus far been described, but by the appended claims and their legal equivalents.

What is claimed is:

1. A metrology tool comprising:

at least one active vibration isolation device; and,
at least one passive vibration isolation device, wherein at least one of the at least one active vibration isolation devices or at least one passive vibration isolation devices, is selected from a group consisting of:

- A) a constrained layer damper and at least one particle or liquid impact damper within a supporting structure of the metrology tool;
- B) at least one noise cancellation transducer arranged to reduce mechanical frequencies by cancelling noise;
- C) at least one noise cancellation transducer arranged to detect a vibration wave and generate an opposite wave having reversed polarity;
- D) at least one acoustic skin with at least one noise cancellation transducer configured to isolate the tool from acoustic vibrations in an environment of the tool;
- E) at least one acoustic transducer applied to at least one of a tool base table and optics' supporting structures; and,
- F) combinations thereof.

2. The metrology tool of claim 1, further comprising:

viscoelastic layers embedded into structural materials of the metrology tool or into a supporting structure of the metrology tool.

3. The metrology tool of claim 1, further comprising:
at least one particle or liquid impact damper in the metrology tool arranged to transmit vibratory energy into granular material or liquid of the damper for dissipation.

4. The metrology tool of claim 1, wherein the passive vibration isolation device isolates frequencies within a frequency range of 0.5 Hz to 150 Hz associated with a pedestal of the tool.

5. The metrology tool of claim 1, further comprising:
at least one viscoelastic layer arranged to dampen vibrations within a frequency range of 50 Hz to 1 kHz and embedded in at least one of a tool bench and an optics supporting structure of the tool.

6. The metrology tool of claim 1, further comprising:
at least one impact damper arranged to dampen vibrations within a frequency range of 1 kHz to 10 kHz and embedded within at least one of tool bench supports and a tool base table of the tool.

7. The metrology tool of claim 1, further comprising:
an active isolation system configured to isolate vibration frequencies with a range of 2 Hz to 150 Hz.

8. The metrology tool of claim 1, further comprising:
an active chuck leveler having sensor controlled actuators configured to maintain horizontal wafer position and minimize stage settling waiting time.

9. A method comprising:

combining at least one active vibration isolation device and at least one passive vibration isolation device into a metrology tool, and,

performing at least one step selected from a group consisting of:

- A) introducing constrained layer dampers and at least one particle or liquid impact damper into a supporting structure of the metrology tool;
- B) reducing mechanical frequencies by cancelling noise using at least one noise cancellation transducer;
- C) cancelling noise by detecting a vibration wave and generating an opposite wave having reversed polarity;
- D) combining at least one acoustic skin with at least one noise cancellation transducer configured to isolate the tool from acoustic vibrations in an environment of the tool;
- E) applying acoustic transducers to at least one of a tool base table and optics' supporting structures; and,
- F) combinations thereof.

10. The method of claim 9, further comprising:
embedding viscoelastic layers into structural materials of the metrology tool or into a supporting structure of the metrology tool.

11. The method of claim 9, further comprising:
transmitting vibratory energy using at least one particle or liquid impact damper in the metrology tool into granular material or liquid of the damper for dissipation.

12. The method of claim 9, further comprising:
associating passive vibration isolation within a frequency range of 0.5 Hz to 150 Hz using a pedestal of the tool.

13. The method of claim 9, further comprising:
embedding at least one viscoelastic layer arranged to dampen vibrations within a frequency range of 50 Hz to 1 kHz in at least one of a tool bench and an optics supporting structure of the tool.

14. The method of claim 9, further comprising:
embedding at least one impact damper arranged to dampen vibrations within a frequency range of 1 kHz to 10 kHz within at least one of tool bench supports and a tool base table of the tool.

15. The method of claim 9, further comprising:
providing an active isolation system configured to handle
vibration frequencies with a range of 2 Hz to 150 Hz.

16. The method of claim 9, further comprising:
providing an active chuck leveler having sensor con- 5
trolled actuators configured to maintain horizontal
wafer position and minimize stage settling waiting
time.

* * * * *

UNITED STATES PATENT AND TRADEMARK OFFICE
CERTIFICATE OF CORRECTION

PATENT NO. : 9,546,946 B2
APPLICATION NO. : 14/361610
DATED : January 17, 2017
INVENTOR(S) : Golovanevsky et al.

Page 1 of 1

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

On the Title Page

Item (54) and in the Specification, Column 1, Lines 1-2 the title of the invention which appears as "METROLOGY TARGET IDENTIFICATION, DESIGN AND VERIFICATION" should appear as --METROLOGY TARGET IDENTIFICATION, DESIGN AND VERIFICATION--.



Signed and Sealed this
Fourteenth Day of March, 2017

Michelle K. Lee

Michelle K. Lee
Director of the United States Patent and Trademark Office