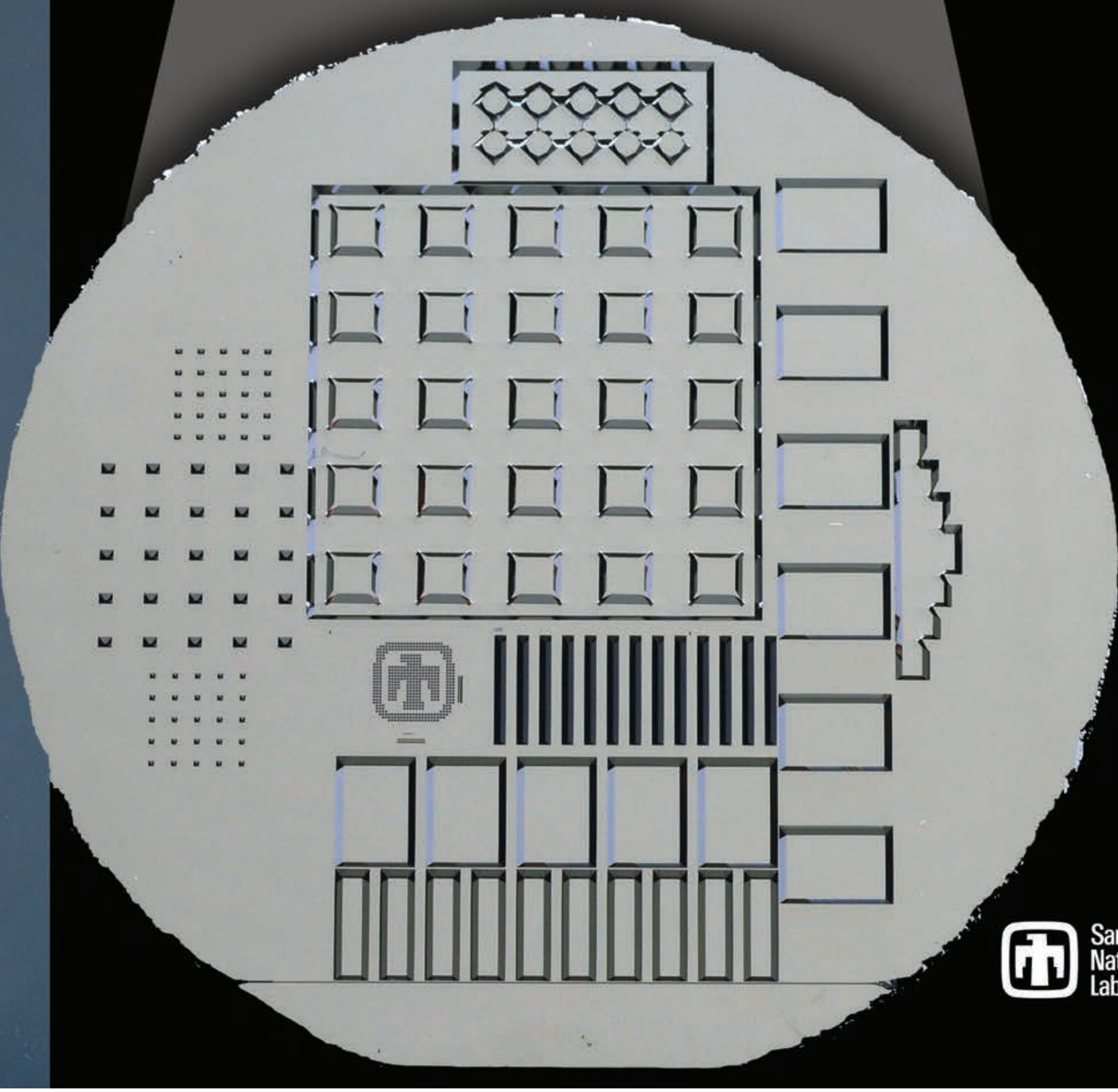
2008 R&D 100 Award Entry Form

# Silicon Micromachined Dimensional Calibration Artifact for Mesoscale Measurement Machines



Sandia National Laboratories

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AFFIRMATION: I affirm that all information submitted as a part of, or supplemental to, this entry is a fair and accurate representation of this product.

Hy D. Tran

**Joint Entry**

Not a joint entry.

**Product Name**

Silicon Micromachined Dimensional Calibration Artifact for Mesoscale Measurement Machines

**Brief Description**

The silicon hybrid artifact is an anisotropic-etched silicon standard that is used as a calibration reference artifact to calibrate vision-based and tactile dimensional metrology equipment.

**When was this product first marketed or available for order?**

Technology first available for licensing to commercial entities in October 2007.

## Inventor or Principal Developers

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## Product Price

Because Sandia National Laboratories is a federal Government-Owned Contractor-Operated entity, it cannot sell products. However, the technology developed by Sandia can be licensed to commercial companies.

## Patents or Patents Pending

US patent application 11/866,177 filed October 2, 2007. A copy of the filing receipt for the patent is in the appendix.

## Primary Function

The Silicon Micromachined Dimensional Calibration Artifact for Mesoscale Measurement Machines is a calibration artifact with an innovative three-dimensional structure suitable for calibration of mesoscale measurement machines that use optical, tactile, or a combination of optical and tactile measuring methods. Mesoscale mechanical components (defined as parts with sizes on the scale of millimeters, but with critical tolerances at the micrometer level) are becoming ubiquitous in society. Examples of mesoscale mechanical components include airbag deployment components and fuel injector assemblies in the automotive industry, and chip-scale packaging and MEMS (Micro-Electro-Mechanical-Systems) assemblies in the electronics industry. Not only do these components contain small critical features, but in a high-volume production environment, they require high-speed inspection. Vision-based metrology (optical probing) is currently the state of the art for inspecting these mesoscale mechanical components.

Production-grade vision devices have a measurement accuracy on the order of 1 micrometer over a measurement range spanning 10-100 mm. The actual repeatability of optical probes, using high magnification optics and subpixel interpolation algorithms, is better than 0.1 micrometer. The dominant error contributor is the lack of a sub-micrometer accurate NIST-traceable (National Institute of Standards and Technology) vision artifact. NIST-traceable vision grid artifacts have accuracy on the order of 1 micrometer. State-of-the-art grid artifacts are made by patterning chrome on glass. The thin layer of chrome results in an essentially two-dimensional structure.

An emerging class of inspection equipment for mesoscale components is a hybrid/multisensor machine, which combines tactile and vision sensors. The calibration of such systems is a new challenge in measurement science, as typical vision system calibration artifacts have a two-dimensional structure and are not suitable for tactile probing.

Because grid artifacts are made by patterning chrome on glass, these patterns are fundamentally two-dimensional, and thus, limited to being calibrated only by optical means. To enable hybrid/multisensor calibration, and to improve accuracy, we have developed a calibration reference artifact based on anisotropic bulk micromachining (a classic MEMS technology).

## Primary Function

*The fundamental innovation over existing chrome-on-glass grids is the use of a nanometrically sharp, yet macroscopically long edge, which can be located using a tactile probe on a very high accuracy Coordinate Measuring Machine (CMM).*

Anisotropic bulk micromachining creates structures with crystallographic angles that are based on intrinsic physical phenomena. The edges created between etch planes are sharp to the nanometer level. The micromachined artifact is made of bulk <100> silicon anisotropically etched in alkaline solution (such as potassium hydroxide), which creates sidewalls at an angle of 54.74 degrees to the <100> plane. This process results in artifacts that have crystallographically accurate edges and lines.

The fundamental innovation over existing chrome-on-glass grids is the use of a nanometrically sharp, yet macroscopically long edge, which can be located using a tactile probe on a very-high-accuracy Coordinate Measuring Machine (CMM). This edge is the same edge as would be seen in an optical probing system. Therefore, the high-accuracy CMM can measure the reference artifact, which can then be used to calibrate optical probing systems to a higher accuracy than with traditional chrome-on-glass grids.

High-accuracy CMM's are routinely used at NIST (e.g., the Moore M48 CMM in NIST's engineering metrology group with a measurement uncertainty on the order of 0.1 micrometer), and are also available as commercial systems (e.g., Hexagon Metrology's Leitz PMM-C Infinity CMM; Zeiss Industrial Metrology's F25 micro CMM; with measurement uncertainties on the order of 0.25 micrometer). These systems are too slow to be used for routine inspection of mesoscale components in a volume manufacturing environment. Chrome-on-glass grids are fundamentally two-dimensional and cannot be probed by these machines.

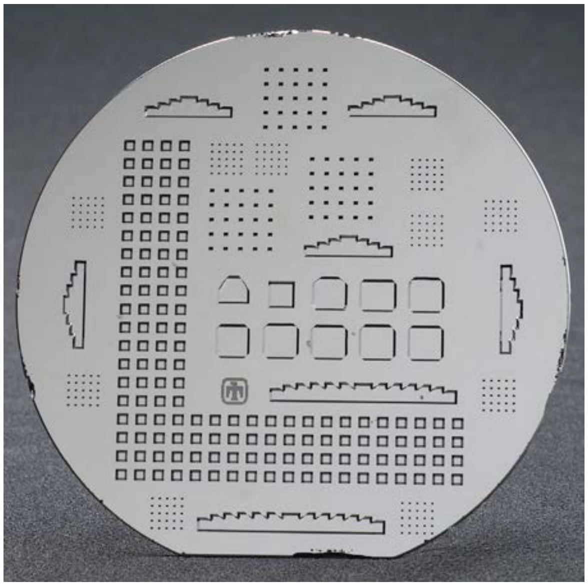

*Figure 1: The Sandia National Laboratories Hybrid Dimensional Calibration Artifact for a 3D workspace. This artifact is made from single crystal silicon, which is first patterned then anisotropic-etched to form a variety of features whose edges are sharp at the nanometer level. This is fabricated on a 150 mm diameter single crystal silicon wafer.*

## Primary Function

*The limiting factor for existing vision-based equipment used in volume manufacturing is the accuracy of the chrome-on-glass grid. When a manufacturer calibrates their existing equipment with our more accurate Silicon Micromachined Dimensional Calibration Artifact, they improve their accuracy by as much as a factor of ten.*

However, these high-accuracy CMM's are ideal for calibrating our Silicon Micromachined Dimensional Calibration Artifact due to its three-dimensional nature.

The limiting factor for existing vision-based equipment used in volume manufacturing is the accuracy of the chrome-on-glass grid. When a manufacturer calibrates their existing equipment with our more accurate Silicon Micromachined Dimensional Calibration Artifact, they improve their accuracy by as much as a factor of ten.

## Product Competitors

Calibration grid plates are available from a number of vendors. One typical grid plate is the OGP626070, which costs approximately $11,000 for a 300×150 mm grid plate. Measurement uncertainty is approximately ±1.5 micrometer.

NIST SRM2800 (Microscope magnification standard) costs approximately $4,000 for a 10 mm scale standard. However, it is not truly a comparable technology, because it is a one-dimensional standard (a line scale standard), and is significantly smaller than grid plates, or our Silicon Micromachined Dimensional Calibration Artifact.

NIST SRM5001 (Grid photomask standard) costs approximately $5,000 for a patterned 150x150 mm grid. However, the line scale widths are 1 micrometer and 2 micrometers, in boxes of 18 micrometers square. These small box and linewidth dimensions make them unsuitable for general purpose vision-based inspection equipment, and the two-dimensional nature does not allow for calibration of tactile or hybrid/multisensor equipment.

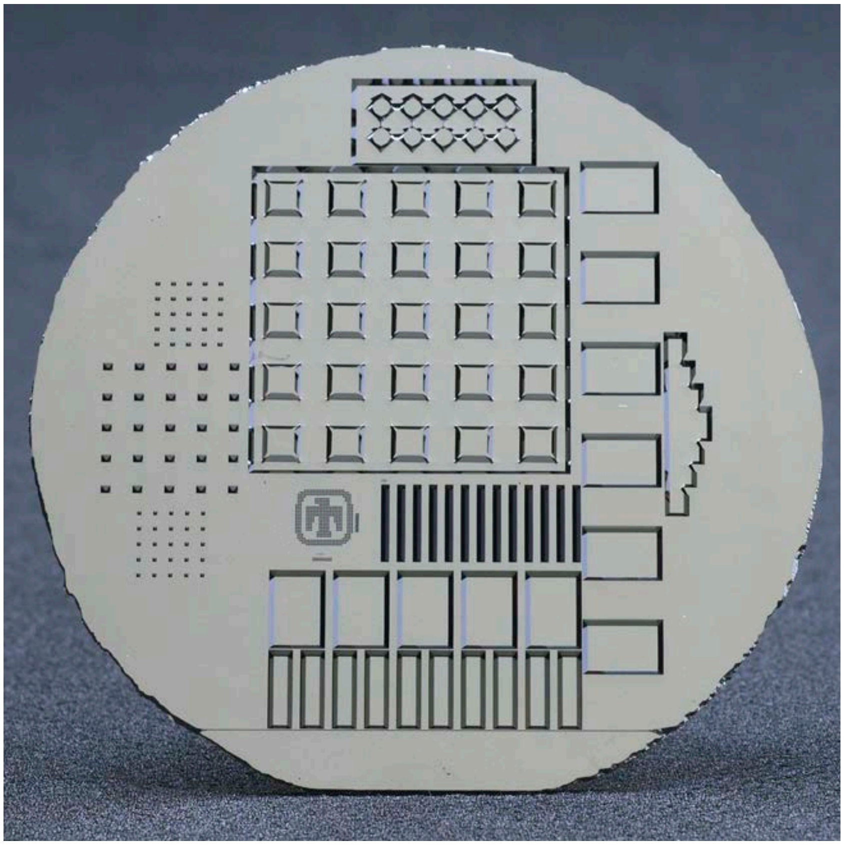

*Figure 2: The first design for a calibration artifact, fabricated to establish feasibility. This is fabricated on a 100 mm diameter silicon wafer.*

## Comparison Matrix

Sandia's hybrid technology offers both improved accuracy, relative to commercial chrome-on-glass grids, and lower cost. This significantly lower cost comes from leveraging existing silicon microfabrication infrastructure. In addition, this new technology is the only one capable of calibrating multisensor machines.

| Technology | Description | Price (with Calibration) | Performance (k=2) | Size | Dimensionality |
|---|---|---|---|---|---|
| Sandia Silicon Micromachined Dimensional Artifact | Anisotropic etched single crystal silicon | $1K (estimated) | Uncertainty = 100 nm (estimated) | 100×100 mm (estimated) | 3D |
| NIST Microscope Calibration Standard | Glass slide with parallel lines. Nominal distances between center of lines are calibrated and vary from 1 micrometer to 5 micrometers. Used for calibrating magnification or scale of microscopes. | $4K | Uncertainty = 20 nm | 10 mm linear | 1D |
| NIST Two-Dimensional Grid Photomask | Glass plate with arrays of boxes. Box dimensions are typically 18 micrometers with 1 or 2 micrometer linewidths; arrays have 3 mm to 5 mm pitch. Used for calibrating photomask/reticle registration tools. | $5K | Uncertainty = 28 nm | 150 x150 mm | 2D |
| OGP Grid Plate | Chrome-on-glass plate with 25 calibrated positions. For calibrating stages of video systems. | $11K | Uncertainty = 1000 nm | 150 × 300 mm | 2D |

## How this Product Improves upon Competitive Products or Technologies

Better measurement accuracy is fundamental to improving product quality, reducing manufacturing costs, and developing new technologies. Not only are we offering improved accuracy and lower cost, but we are also enabling 3D and multisensor calibration.

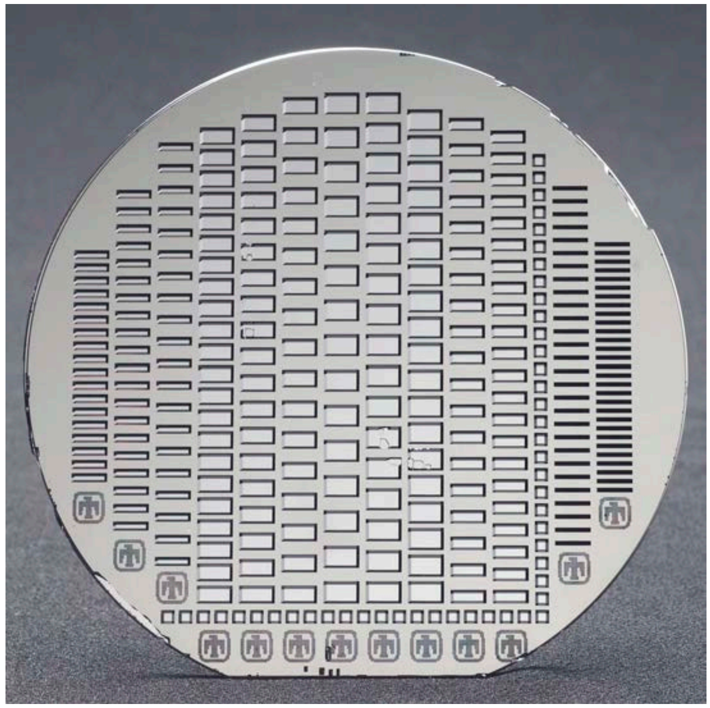

*Figure 3: A less expensive calibration artifact can be fabricated by putting multiple gauges on the same wafer, which are then diced and separated (as shown in Figure 3). This is fabricated on a 150 mm diameter single crystal silicon wafer.*

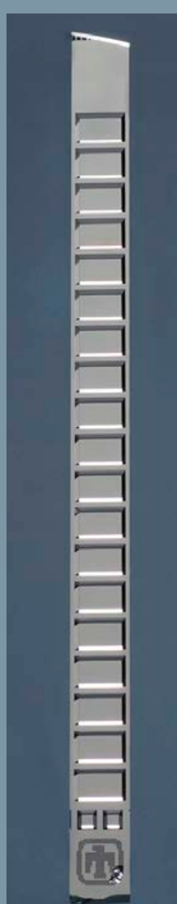

*Figure 4: A Silicon Micromachined Dimensional Calibration Artifact"step gauge" diced from a wafer such as shown in (Figure 2). The wafer shown in Figure 2 can be diced to make 13 "step gauges."*

## Principal Applications

The silicon micromachined dimensional calibration artifact allows for calibration of vision-based inspection equipment, hybrid/multisensor inspection systems, and micro-Coordinate Measuring Machines.

In addition, the improved accuracy of the silicon hybrid artifact relative to chrome-on-glass grids enables manufacturers to improve the accuracy of their *existing* equipment.

## Other Applications

The Silicon Micromachined Dimensional Calibration Artifact's sole purpose is to be used as a calibration reference to calibrate vision-based and tactile dimensional metrology equipment. Additionally, it has the unique ability to improve the accuracy of a user's existing equipment at a relatively low cost. With its superior sharp and strong edge, increased accuracy, and cost savings, it has the potential to become the leading technology in small-scale industrial measuring systems.

## Summary

With increasing miniaturization in manufacturing (such as nozzles in fuel injectors, watch parts, inkjet printer parts, or other small scale parts), it is necessary to improve inspection accuracy while maintaining the ability for high-volume manufacturers to inspect at high speeds. The accuracy of vision metrology systems used to inspect these small-scale parts is limited by the accuracy of the calibration artifact.

Our invention has both lower cost and up to ten times better accuracy than other vision calibration artifacts. Purchasing, installing, and qualifying new equipment is expensive. With our invention, a user can improve their accuracy by simply recalibrating their equipment, using the Silicon Micromachined Dimensional Calibration Artifact as the calibration standard. The user would operate and calibrate their equipment in the same fashion as before, and potentially improve inspection accuracy by a factor of ten.

Finally, because the Silicon Micromachined Dimensional Calibration Artifact is three-dimensional in nature, it provides a new capability for multisensor system calibration.

## Contact person to handle all arrangements

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## Appendix: Patent Filing Receipt

Hy D. Tran, Andre A. Claudet, Andrew D. Oliver, "Mesoscale Hybrid Calibration Artifact," U. S. Patent Filing Receipt, application number 11/866,177, October 2, 2007.

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| APPLICATION NUMBER | FILING or 371(c) DATE | GRP ART UNIT | FIL FEE REC'D | ATTY.DOCKET.NO | TOT CLAIMS | IND CLAIMS |
|---|---|---|---|---|---|---|
| 11/866,177 | 10/02/2007 | 2622 | 1080 | SD10299/S109335 | 21 | 2 |

**CONFIRMATION NO. 6670**

20567
SANDIA CORPORATION
P O BOX 5800
MS-0161
ALBUQUERQUE, NM 87185-0161

**FILING RECEIPT**

*OC000000026419202*

Date Mailed: 10/25/2007

Receipt is acknowledged of this non-provisional patent application. The application will be taken up for examination in due course. Applicant will be notified as to the results of the examination. Any correspondence concerning the application must include the following identification information: the U.S. APPLICATION NUMBER, FILING DATE, NAME OF APPLICANT, and TITLE OF INVENTION. Fees transmitted by check or draft are subject to collection. Please verify the accuracy of the data presented on this receipt. **If an error is noted on this Filing Receipt, please write to the Office of Initial Patent Examination's Filing Receipt Corrections. Please provide a copy of this Filing Receipt with the changes noted thereon. If you received a "Notice to File Missing Parts" for this application, please submit any corrections to this Filing Receipt with your reply to the Notice. When the USPTO processes the reply to the Notice, the USPTO will generate another Filing Receipt incorporating the requested corrections**

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**Power of Attorney:** The patent practitioners associated with Customer Number 020567

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**Domestic Priority data as claimed by applicant**

**Foreign Applications**

**Projected Publication Date:** Request for Non-Publication Acknowledged
**Non-Publication Request:** Yes
**Early Publication Request:** No
**Title**

Mesoscale Hybrid Calibration Artifact

**Preliminary Class**

348

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page 1 of 3

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*The silicon artifact presents an edge that is very sharp, but strong enough for mechanical probing. There is a very good possibility that this technology will allow machine vision metrology to significantly reduce the uncertainty for a number of feature types.*

## Quote from Dr. Theodore Doiron, group leader, Engineering Metrology at NIST:

While machine vision is increasingly popular because of its speed, there has always been a lower bound on any uncertainty because of diffraction effects at the edges of features. The semiconductor industry has spent large amounts of money on the similar problem of finding the true edge of a chrome line on a mask or wafer by microscopy. There are a number of standard reference linewidth producers, but the standards have very narrow lines and the cost is significant; more than the cost of many industrial measuring systems. The silicon artifact presents an edge that is very sharp, but strong enough for mechanical probing. There is a very good possibility that this technology will allow machine vision metrology to significantly reduce the uncertainty for a number of feature types.

Regards,
Ted Doiron

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**Quote from Mr. John Horwell, senior metrologist at Hexagon Metrology:**

We have always struggled in the past relative to the verification and correlation between hybrid systems that had tactile and optical sensors. We used certified glass scales for the optical portion and step gauges for the tactile portion. In essence we had to verify our CMM twice – once with tactile, and then using long glass scales. We also measured master grid plates via optics using line steps and other geometric figures that we etched on the surface of a glass plate. We used a ring gauge as a means to establish correlation between optical and tactile sensors, as well as stacked gauge blocks that could be measured in the Z-direction easily by both sensors.

So as a manufacturer of hybrid instruments we look forward to the possibility of being able to better quantify our two sensors and specifically when they are used in tandem. So hopefully we will have a chance to participate in your research and to provide feedback as to our results. Having a test piece that is capable of being measured with both and quantified is in itself exciting.

John Horwell (john.horwell@hexagonmetrology.com)
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