

Featuring

Achieving 17-Picometer Resolution Sony Laserscale Products for the Next Generation of Innovative Manufacturing

Scale resolution

Achieving a resolution of 17 picometers

Laserscale stability

Interpolator

Future developments

The Laserscale Lineup

LASERSCALE®

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One nanometer (nm) is 10^{-9} meters.
One picometer (pm) is 10^{-12} meters.

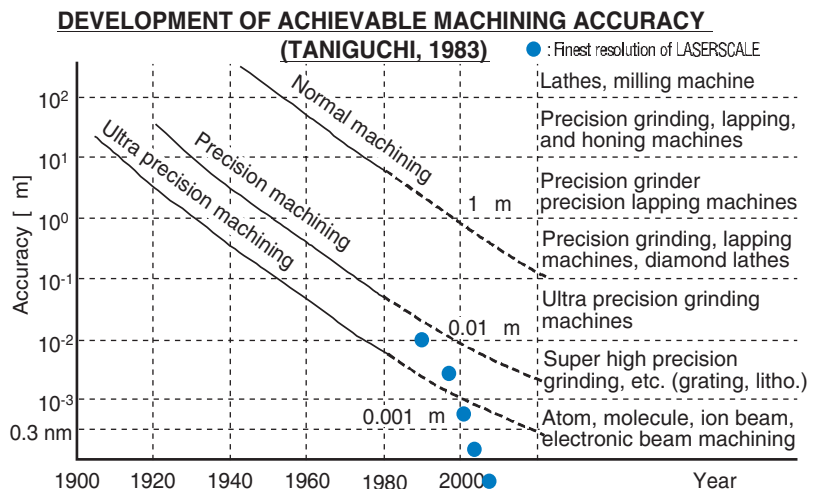
Laserscale is an ultra-precision measuring technology indispensable for modern innovative manufacturing. Sony Manufacturing Systems Corporation develops and manufactures the Laserscale products, which use laser beams to achieve picometer level measurement (one picometer is one trillionth of a meter). The Laserscale products are indispensable in leading-edge technology manufacturing where ultra-precision measurement is required. Applications range from next generation semiconductor manufacturing to Blu-ray discs and lenses for digital cameras. This issue of CX-News introduces Sony's Laserscale technology.

Scale Resolution

Interferometers and scales are used in ultra-precision machining equipment and semiconductor manufacturing equipment. While interferometers have the major advantages that they can be used in line and that they have good linearity, they have the disadvantage that when used in air, the laser wavelength used as the reference for measurement can change with air disturbances and changes in air pressure. In contrast, scales are difficult to use in line, and their linearity is inferior to that of inter-

ferometers due to bending of the scale itself and errors when recording readings. However, since the measurement reference consists of a solid state scale, they are resistant to environment influences and provide a superlative stability appropriate to their resolution. Therefore, although interferometers were used previously, by the early 1990s, when primary signal pitches in scales became finer than the signal pitches in interferometers, scales became the instrument of choice. Recently, since mechanical hardnesses have increased and error compensation has become easier, currently almost all equipment is controlled with these mechanical scales. Figure 1 shows Dr. Norio Taniguchi's predictions for progress in mechanical accuracy and the corresponding changes in scale accuracy. Despite mechanical accuracy already having reached the atomic level, there are strong demands for increased accuracy from semiconductor manufacturing equipment development divisions, where line widths are narrowing rapidly, magnetic disks, in which the recording density increases steadily, and optical disc write equipment, in which new recording methods compete fiercely. To respond to these demands, Sony has combined their Laserscale technology with a new interpolator that can interpolate to 1/8000 and has achieved a resolution of about 17 pm.

Figure 1 Required Mechanical Accuracy and Laserscale Resolution



Laserscale Achieves a Resolution of 17 Picometers

Sony has increased the resolution with a unique optical system that increases the number of diffractions and has acquired a 138 nm signal wavelength in their highest resolution product. In this optical system, the primary signal wavelength is 1/4 of the scale lattice wavelength and, by increasing the diffraction efficiency by using a volumetric phase hologram for the diffraction grating used as the scale, Sony is able to achieve a high signal quality. Furthermore, this optical detection system is designed so that error does not occur even if there are variations in semiconductor laser wavelength due to temperature changes or changes in pressure and humidity, which change the index of refraction of air. The scale is made from a Neo ceram that has a low coefficient of thermal expansion that is about 1/10 that of ordinary glass.

Figure 2 shows the detection principles used by the Laserscale products. The laser beam emitted from the semiconductor laser active area passes through a polarized beam splitter (PBS) and is divided into two beams, the P wave and the S wave. The split laser beam impinges on a hologram lattice in which a 550 nm period pattern has been engraved on the glass surface. The laser beam is diffracted and then impinges on a mirror with a quarter wave plate. When the beam is reflected from the mirror, the S wave is converted to a P wave, and the P wave is converted to an S wave. These beams return to the hologram lattice and are diffracted a second time. Since the P and S waves have been switched, the two beams, which return to the polarized beam splitter, do not return to the active (emission) area but rather proceed to the detector and are combined. Since the two optical paths are symmetrical in the left/right direction, the influences of atmospheric fluctuation and pressure changes are cancelled.

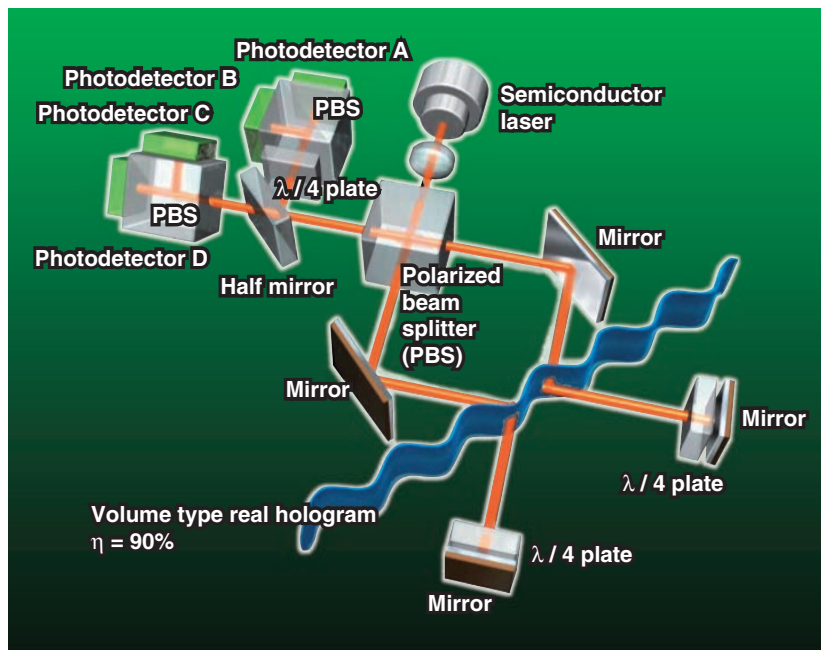
The double diffraction means that the synthesized wave switches between dark and bright four times each time the hologram lattice moves 550 nm, which is one period of the lattice.

As a result, a precise primary signal with a period of 138 nm is detected by the photodetector.

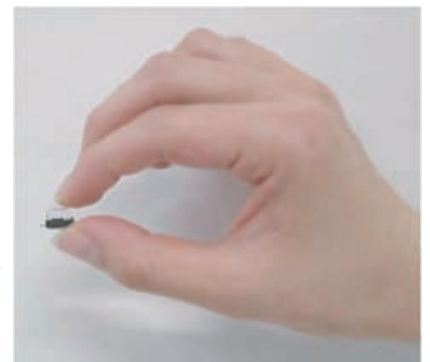
That signal has a sinusoidal form, and a 2-phase primary signal can be extracted optically. This primary signal is divided electronically by the interpolator's signal-processing LSI. A resolution of 34 pm is achieved by dividing by 4000 and a resolution of 17 pm is achieved by dividing by 8000.

A highly reliable 790 nm wavelength Sony laser diode is used in the optical block. Furthermore, a special-purpose IC that integrates the light source, polarized beam splitter, and photodetectors is used to create a compact detector unit.

Figure 2 Laserscale Detection Principles



Integration



Laserscale Stability

As we mentioned before, scales are superior to interferometers.

The main reasons drift occurs are temperature, humidity, the effects of stress on the mounting, and long-term changes in the gauge itself. While these also depend on the usage environment, in general, the influence of temperature is large. To minimize drift, a scale made from materials with a small coefficient of thermal expansion is selected. Also, the detector head, which is a source of heat, is designed for minimal power consumption. When accuracy enters the nanometer range, humidity becomes a problem. This is because moisture can be absorbed if the optical and other components in the gauge itself are mounted with adhesives. Also, inadequate hardness in the detector block can cause drift over long time periods.

Laserscale stability is verified by observing the signal drift in the usage environment. The scale and head are mounted on a block. As shown in figure 3, stability is within ± 1 nm for measurements taken over a 40-day period. Laserscale also provides a ± 0.1 nm stability over an 8-hour period.

Interpolator

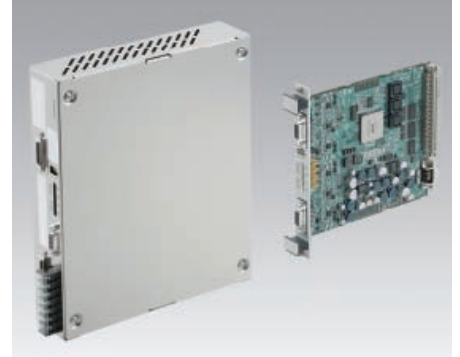
The interpolator converts the sinusoidal primary signal voltage acquired from the detection head to position information by finely interpolating (dividing) that signal.

The scale accuracy is determined by the variations in the wavelength and the interpolation error that occurs during each primary signal period. Since there are no variations in the wavelength in an interferometer, only the interpolation error is a problem.

In a scale, there are cases when the variations in wavelength during recording can be averaged and ignored if the average phase of multiple lattices is detected. For interpolation accuracy, variations occur when the two-phase waveform, which is the primary signal, is displaced relative to an ideal sine wave. That is, both errors in the offset and phase of the two-phase sine wave output and errors in the amplitude of the signal cause interpolation errors. Therefore, highly accurate signal correction is required to achieve highly accurate interpolation.

This signal distortion problem occurs when the measurement light and the reference light are not completely isolated, even in ordinary optical interferometers. Therefore it is not

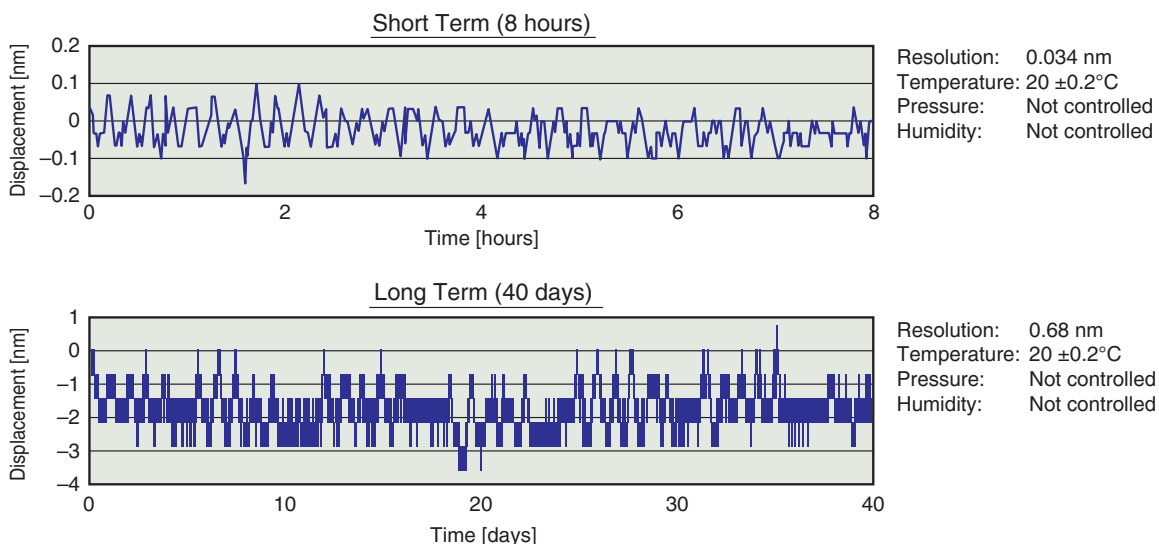
Photograph 1 Interpolator



easy to require sub-nanometer accuracy in an optical interferometer, and the correction function is critical. The interpolator performs the primary signal correction described above. The interpolator calculates the phase from the four signals with phases that differ by 90 degrees each that are output by the head. If the signal center and the zero calculated by the interpolator do not agree, an interpolation error with the same period as the primary signal wavelength has occurred. If the phase difference is not 90 degrees and if the primary signal amplitude is not equal, an interpolation error of 1/2 has occurred.

The magnitudes of these errors can be expressed as follows. The signal amplitude

Figure 3 Laserscale Static Stability When the ultrahigh accuracy 138 nm signal wavelength is used.



is expressed as R, and the error caused by the signal center phase displacement, d, is the DC error. The error when the signal amplitudes are not the same is the gain error, and the error due to the deviation of the inter-signal phase from 90 degrees, α , is the phase error.

DC error: $\Delta\theta \approx \frac{d \sin\theta}{R}$

Gain error: $\Delta\theta \approx \frac{(1-\alpha)}{2} \sin(2\theta)$ $\alpha=R_i/R_r$

Phase error: $\Delta\theta \approx \alpha \frac{1-\cos 2\theta}{2}$

θ : Scale signal phase

When we compute the amount of error, it becomes clear that the primary signal error must be made extremely small. For example, if we want to hold the error to 0.1% of the primary signal wavelength, the DC error must be held to be within 0.3% of the amplitude. It is necessary to perform extremely accurate correction at all times to increase the interpolation accuracy. It is possible to achieve a ± 50 pm interpolation accuracy by monitoring and correcting the primary signal DC components for each primary signal and the gain in the interpolator.

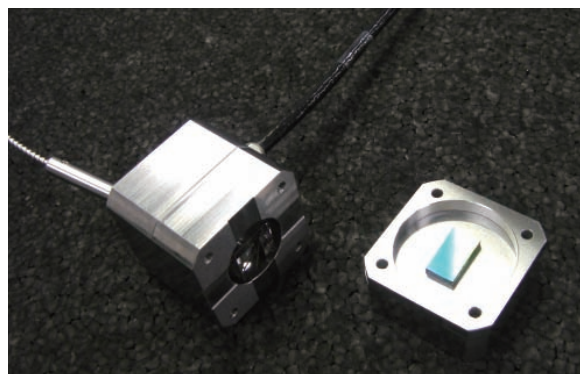
Future Developments

Higher resolution and higher accuracy will be strongly desired due to increasing memory capacities, and by 2010, there will be a demand for 10 pm accuracy. To reach this region, we may have to perform measurements in a vacuum, and not only

the current single line measurement, but area measurement, that is, two-dimensional measurement, will also be required.

The Sony Laserscale products will continue to evolve to respond to these changing market demands.

Photograph 2 Next Generation 2D Laserscale



- Minimum resolution: 31.25 pm
- Number of measurement axes: 2 axes (two dimensions)
- High-accuracy origin: Short interval absolute
- Operating environment: Air or vacuum
- Stability: ± 2 nm/month

* Sony Manufacturing Systems Corporation will exhibit Laserscale at SEMICON Japan (December 3 to 5, 2008, Makuhari Messe). Please visit the Sony Manufacturing Systems Corporation booth.

Table 1 Laserscale Models

Model	Optical system	Signal wavelength	Minimum resolution	Main applications
BL series	Transmissive integrated	400 nm	50 pm	Semiconductor inspection equipment, LCD lithography equipment, high-precision lathes, discharge machining equipment
BH series	Reflective	250 nm	31.25 pm	Hard disk drive manufacturing equipment, magnetic head detection equipment
BS series	Transmissive	138 nm	17.25 pm	Semiconductor lithography equipment, detectors, optical disc cutters, aspheric surface machining equipment, EB tracing equipment

Photograph 3 The Laserscale Product Line



BL series

BH series

BS series