RECOMMISSIONING THE LENGTH SCALE INTERFEROMETER AT THE NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY AND APPLICATION TO LENGTH TRACEABILITY FOR NANOELECTRONIC MANUFACTURING

Ronald G. Dixson[a], John A. Kramar[a], Thomas W. LeBrun[a], Olivier Marie-Rose[b], William B. Penzes[a]

[a]National Institute of Standards and Technology, Gaithersburg, Maryland, United States of America

[b]Prometheus Computing, LLC., Cullowhee, North Carolina, United States of America

INTRODUCTION

Many principles of dimensional metrology and instrument design are applicable across length scales ranging from macroscale parts measured using coordinate measuring machines (CMMs) down to nanoscale features imaged using electron microscopy. Displacement interferometry, for example, is applicable across this whole range, from nanometers to meters.

The National Institute of Standards and Technology (NIST) Length Scale Interferometer (LSI) is an instrument originally intended for dimensional metrology of line scales up to 1 m, but it can also be applied to measurements of a few micrometers. It has been previously used to support calibration of several generations of the NIST photomask standard, beginning with NIST Standard Reference Material (SRM) 474 – as shown in Figures 1A and 1B.

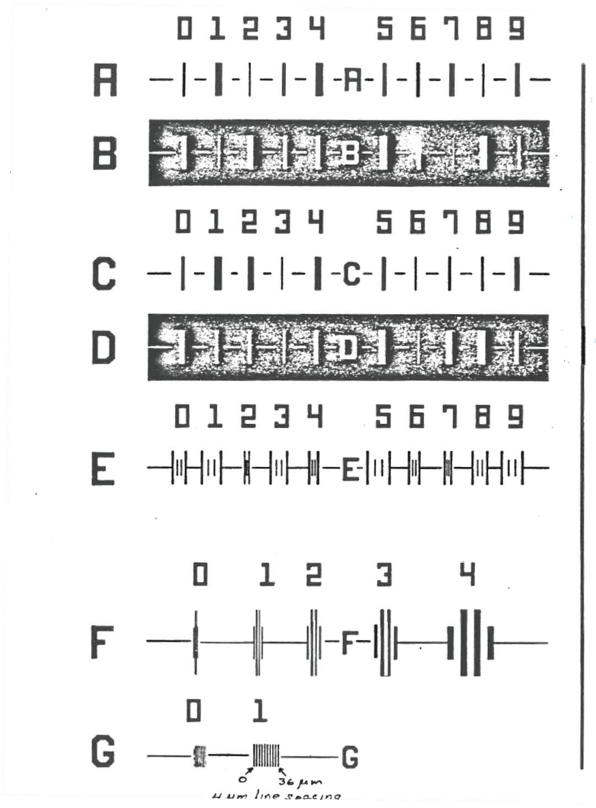

FIGURE 1A. Schematic of pattern layout on NIST SRM474. The G1 grating with a 4 µm pitch was selected for monitoring.

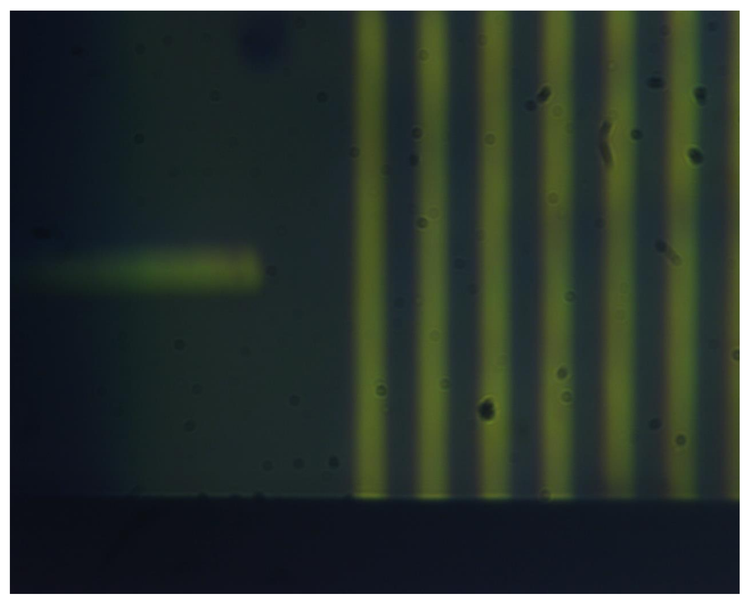

FIGURE 1B. Optical image showing a portion of the G1 array on NIST SRM474.

We are in the midst of recommissioning the LSI, and in the process are validating its performance at the microscale against these historical data in support of future applications to nanoelectronic manufacturing. Some potentially relevant applications would be LSI measurements on samples such as photomasks, grid plates, and stage micrometers. Additionally, LSI measurements could be relevant to the calibration of other manufacturing or metrology instruments.

REALIZATION OF THE SI METER

- 1889 until 1960: the International System of Units (SI) meter was defined by a physical meter bar artifact kept at the International Bureau of Weights and Measures (BIPM) outside of Paris, France.
- National Metrology Institutes (NMIs) such as NIST (then the National Bureau of Standards, NBS) maintained their own national standards and used optical comparators to achieve traceability to the SI meter.
- 1960: The meter was redefined to be based on the vacuum wavelength of the 605 nm spectral line of Krypton. The invention of the laser in 1960 quickly led to the feasibility of reliable displacement interferometry over distances exceeding one meter, and the 633 nm helium-neon laser became a commonly used secondary standard for realization of the meter.
- 1983: The definition of the meter was revised again in 1983 to be given by a fixed value of the speed of light and the realization of the SI second

THE NIST LENGTH SCALE INTERFEROMETER

The NIST LSI was first commissioned in 1966, combining 633 nm displacement interferometry with a photoelectric microscope and line-centering position feedback for partially automated measurement of one-dimensional scales [1]. A simplified block-diagram schematic of the major subsystems and components of the NIST LSI is shown in Figure 2. A photo of the original core mechanical components of the LSI is shown in Figure 3.

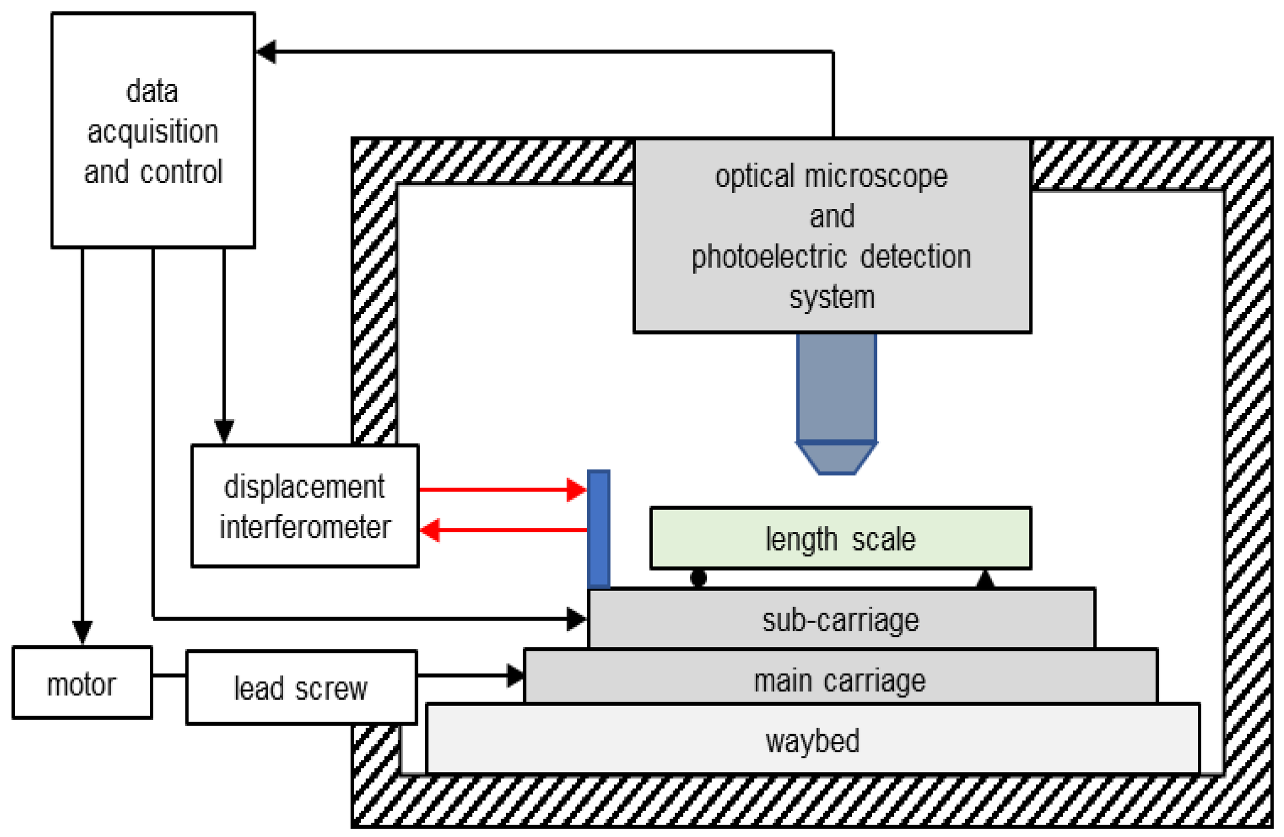

FIGURE 2. Simplified schematic of the NIST LSI.

LSI Monitor/Control Samples: Long End of Range

To monitor and maintain the performance of the LSI over the long end of the measurement range, various control samples are used. Two of the most important ones are:

(1) A 1000 mm Invar scale that has been in use since 1965, before the beginning of the LSI.

(2) A 508 mm steel scale that has been in use since 1982.

LSI Monitor/Control Samples: Short End of Range

The relative strength of the LSI is over longer measurement distances, but it is capable of measurements over ranges as short as a few micrometers. Short-range monitoring is less important, due to the much smaller length dependent error contributions. Nevertheless, a variety of artifacts are also used for short-range monitoring. One of these is a 4 µm pitch grating on one of the first generation NIST chromium-on-silica photomask standards, SRM 474.

The G1 linear grating consists of ten features and thus includes intervals up to 36 µm. The first LSI measurements of this grating were performed in 1984, and the sample was periodically remeasured through 1997. For recommissioning purposes, we have selected a 32 µm interval and extended the monitor history. The prior and recent measurements are shown in Figure 4.

MEASUREMENT UNCERTAINTIES

Measurement uncertainties are usually separated into two categories:

(1) Type A components are those evaluated statistically – such as from observed reproducibility. In the prior work, this contribution was approximately in the range of 30 nm to 50 nm (coverage factor k = 1) for long range measurements.

(1) Type B components are evaluated non-statistically by prior measurements, physical models, or heuristic arguments [2]. The contributions to the length-dependent relative standard uncertainty component were evaluated to be approximately 5.0×10^{-8}, as shown in Table 1.

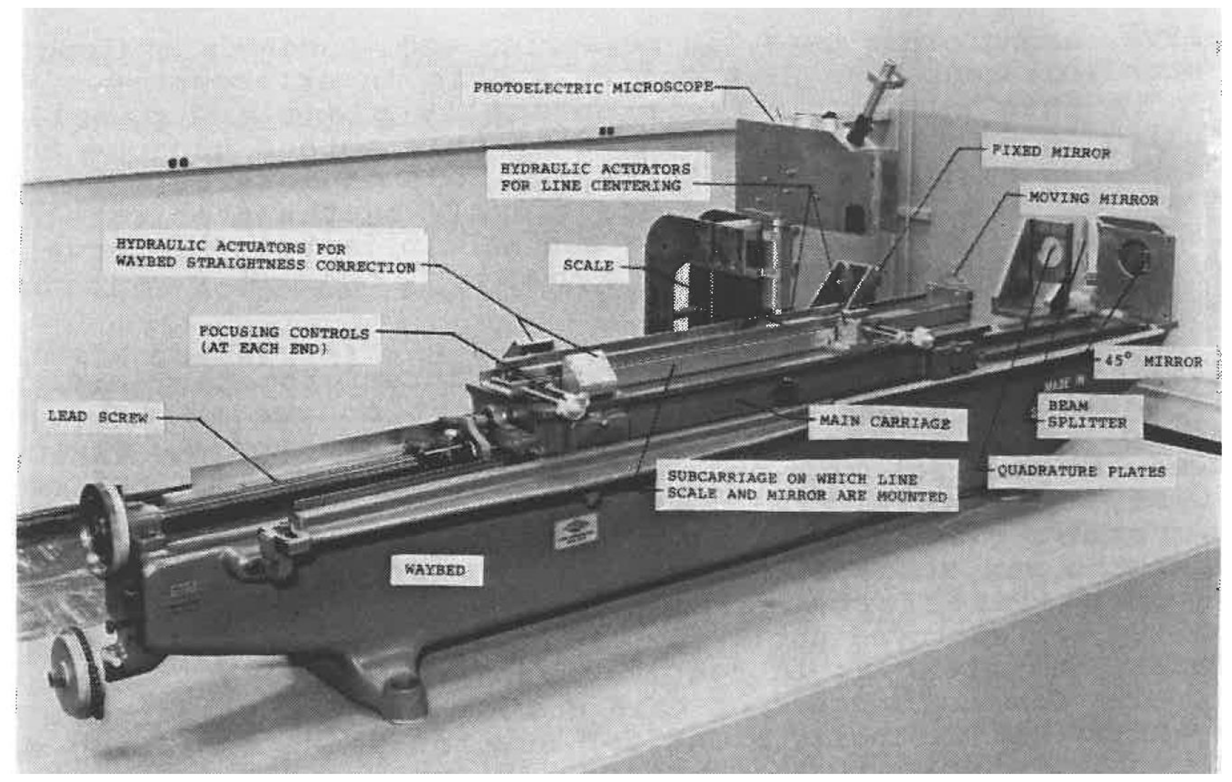

FIGURE 3. Photo of original implementation of the LSI. Many subsequent modifications and additions Have been made, but the core mechanical components of the system remain the same.

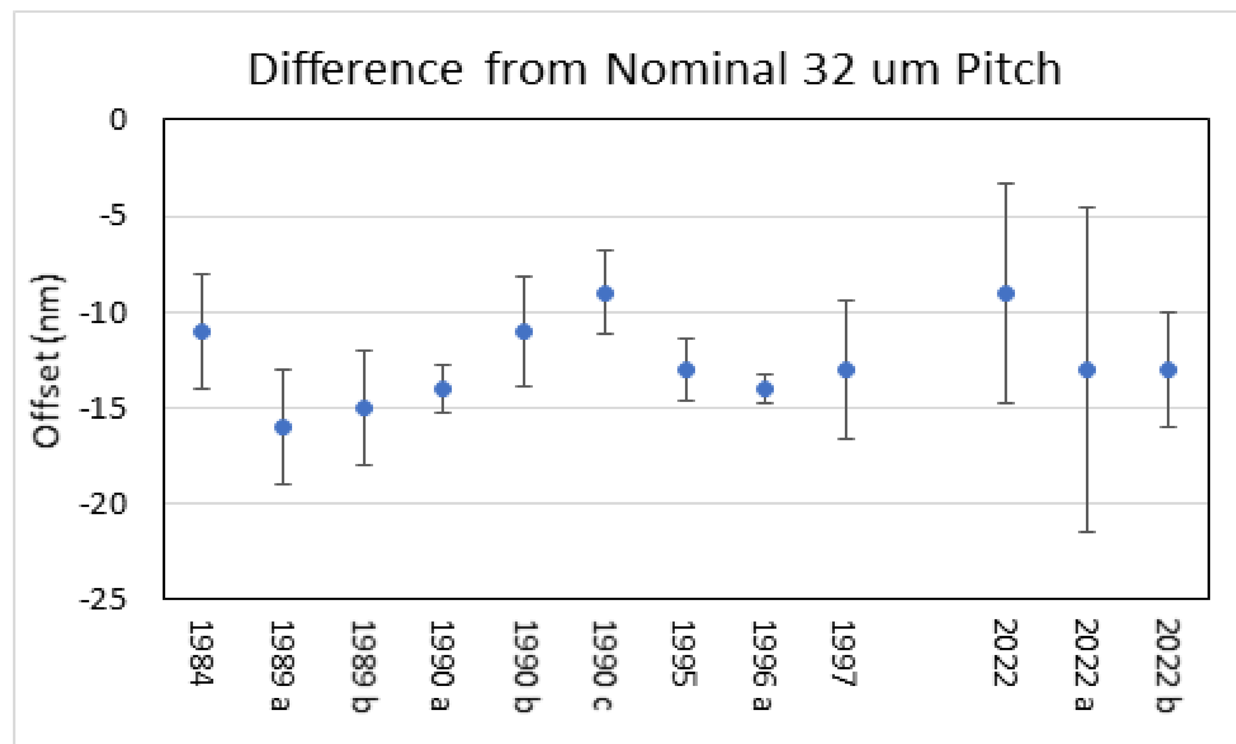

FIGURE 4. Monitor history of LSI measurements on 32 µm interval on SRM474. Error bars represent standard uncertainty (k = 1).

TABLE 1. Type B components of prior uncertainty in LSI measurements. This will be validated and further refined during LSI recommissioning.

Parameter	Requirement for 10^{-8} Relative Uncertainty	Contribution to Process Uncertainty in Prior Operation
Vacuum Wavelength	1×10^{-8}	2×10^{-8}
Refractive Index Equation	1×10^{-8}	2×10^{-8}
Air Temp	0.01 °C	0.5×10^{-8}
Pressure	4 Pa	2×10^{-8}
Relative humidity	1.2 % RH	1×10^{-8}
CO_2 content	67×10^{-6}	1×10^{-8}
Interferometer Alignment	0.14 mm/m	2×10^{-8}
Scale Temp - Steel	0.001 °C	2×10^{-8}
Quadrature Sum	--	5×10^{-8}

SUMMARY AND CONCLUSIONS

The NIST LSI was upgraded multiple times during regular use from 1966 until 2015. A larger overhaul and recommissioning has since been undertaken and is nearing completion. Our recent observations on SRM474 suggest that the noise floor is still high relative to historical measurements. We continue to work on upgrades and will extend the renewed monitor history to include long length scales.

REFERENCES

1. J. Beers and W. Penzes, “The NIST Length Scale Interferometer,” Journal of Research of the National Institute of Standards and Technology 104, 225 (1999).
2. B. N. Taylor and C. E. Kuyatt, “Guidelines for Evaluating and Expressing the Uncertainty of NIST Measurement Results,” NIST Technical Note 1297 (2004).