A NEW HORIZON: USING HEAT TO MEASURE DISTANCE IN HIGH PERFORMANCE METROLOGY SOLUTIONS

Roy Bijster[1,2], Hamed Sadeghian[2], and Fred van Keulen[1]

[1]*Department of Precision and Microsystems Engineering (PME), Delft University of Technology, Mekelweg 2, 2628CD, Delft, The Netherlands*

[2]*Nano-Opto-Mechanical Instruments (NOMI), Dept. of Optomechatronics, Netherlands Organisation for Applied Scientific Research TNO, Stieltjesweg 1, 2629 CK, Delft, The Netherlands*

Presenter's e-mail address: r.j.f.bijster@tudelft.nl

In a continuing quest to further reduce the minimal feature size in semiconductor devices, the need for high resolution inspection and metrology increases exponentially [1]. In today's process flow, wafers are taken out of the fabrication line to be inspected using tunneling electron microscopy (TEM) for high resolution, in-die metrology. However, this technique is destructive, slow and labour intensive [1] and can therefore not be applied as an integral part of fabrication. Non-destructive alternatives, such as scanning tunneling microscopy (SEM) and scatterometry are used to complement the TEM measurements, but these cannot compete in terms of resolution, and in the case of scatterometry only result in mean parameter values [2]. To meet the metrology requirements of today and those of the future, new inspection techniques are required that can offer sub-nanometer resolution, are non-destructive and offer high throughput.

Atomic force microscopy (AFM) in particular, may offer a viable solution. It has the potential of atomic resolution, and by massive parallelization [3] can cover large areas to create statistically relevant data. The topography of the sample is derived from the mechanical response of a probe to atomic forces. This however, requires (intermittent) contact with the sample. Especially high aspect ratio features, e.g., FinFETs, can suffer from damage caused by significantly increased mechanical loads when the probe suddenly encounters such a feature [4].

Instead of relying on the atomic force, heat transferred between a probe and the sample may offer a non-contact, high resolution scanning probe technique, as illustrated by the following examples.

For example, in ambient conditions heat is most dominantly transferred between the probe and the sample by means of conduction through the interstitial air layer. In vacuum conditions, heat is transferred mainly through radiation. Near-field effects, such as interference, photon tunneling and phonon tunneling enhance the flux to beyond the black body limit at distances that are smaller than Wien's wavelength (approximately 10 µm at room temperature). Using the models provided by [5] and [6], respectively, the sensitivity of a distance measurement based on heat transfer is derived. The results of which are plotted in Fig. 1 and Fig. 2.

It is instructive to consider a distance sensor that is comprised of a calorimeter with a 1 nW resolution. Such performance results in both environments in an equivalent sub-nanometer distance resolution. If such performance can be realized, thermal scanning probes are a viable solution for non-contact distance measurement and profilometry. Such distance sensors also find application when interferometry and capacitive sensors do not offer a robust solution, e.g., when the sample is neither sufficiently reflective, nor conductive.

For verification and validation of these concepts, a development platform has been built. This setup accurately positions a silica prism with respect to a microscopic calorimeter. By applying a closed loop, optical read-out and optical modulation technique, a resolution of ≤ 20 pW and an accuracy of 2.13 nW are obtained [7]. This results in a theoretical distance resolution and accuracy in the order of picometers for both ambient and vacuum environments.

In this paper, we report on initial experimental findings that are obtained under ambient conditions to demonstrate the true potential of the technique and the development platform.

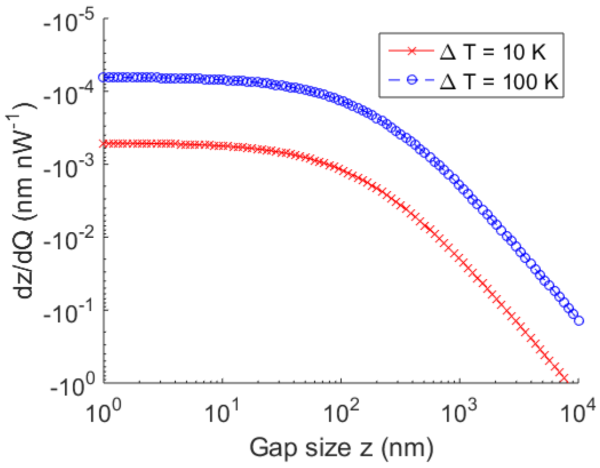

Fig.1: Sensitivity of derived distance to measured flux dz/dQ for heat transferred through conduction. Here a disc of $20\ \mu m$ *diameter is assumed, parallel to a flat substrate. The gas is assumed to be air at* $1\ atm$ *pressure. Heat transfer model is derived from [5]. The sample is assumed to be at 293 K, while the probe is at* $293\ K + \Delta T$.

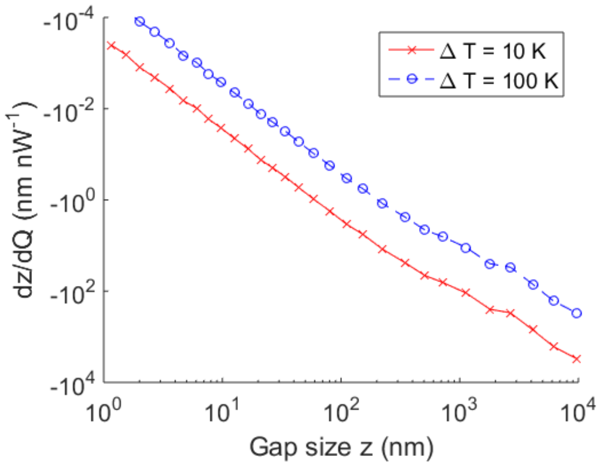

Fig. 2: *Sensitivity of derived distance to measured flux dz/dQ for heat transferred by near-field radiation. The probe is a* $20\ \mu m$ *diameter sphere. Both substrate and probe are made of* SiO_2. *Heat transfer model is derived from [6]. The sample is assumed to be at 293 K, while the probe is at* $293\ K + \Delta T$. *Figure was earlier published elsewhere[7].*

ACKNOWLEDGMENTS

This program is financially supported by the TNO early research program 3D Nano Manufacturing Instruments.

REFERENCES

[1] Ma, Z. (2016). Smart metrology for continuing Moore's law scaling. In M. I. Sanchez (Ed.), *SPIE Conference Proceedings Volume 9778: Metrology, Inspection, and Process Control for Microlithography XXX* (in press). San Jose, CA, USA: SPIE Digital Library.

[2] Raymond, C. J., Naqvi, S. S. H., & Mcneil, J. R. (1997). Resist and etched line profile characterization using scatterometry. *Proc. SPIE 3050, Metrology, Inspection, and Process Control for Microlithography XI*, *3050*(1), 476–486. doi:10.1117/12.275944

[3] Sadeghian, H., et al. (2015). Development of a detachable high speed miniature scanning probe microscope for large area substrates inspection. *Review of Scientific Instruments*, *86*(11), 113706. doi:10.1063/1.4936270

[4] Keyvani, A., Sadeghian, H., Goosen, H., & van Keulen, F. (2015). Transient tip-sample interactions in high-speed AFM imaging of 3D nano structures. In *Proc. SPIE 9424, Metrology, Inspection, and Process Control for Microlithography XXIX* (Vol. 9424, p. 94242Q). doi:10.1117/12.2185848

[5] Masters, N. D., Ye, W., & King, W. P. (2005). The impact of subcontinuum gas conduction on topography measurement sensitivity using heated atomic force microscope cantilevers. *Physics of Fluids*, *17*(10), 100615. doi:10.1063/1.1932313

[6] Rousseau, E., *et al.* (2009). Radiative heat transfer at the nanoscale. *Nature Photonics*, *3*(9), 514–517. doi:10.1038/nphoton.2009.144

[7] Bijster, R. J. F., Sadeghian, H., & Keulen, F. van. (2016). Non-contact distance measurement and profilometry using thermal near-field radiation towards a high resolution inspection and metrology solution. In *SPIE Conference Proceedings Volume 9778: Metrology, Inspection, and Process Control for Microlithography XXX* (in press). San Jose, CA, USA: SPIE Digital Library