Nanometric layer thickness detection via spatial mode projection

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ABSTRACT

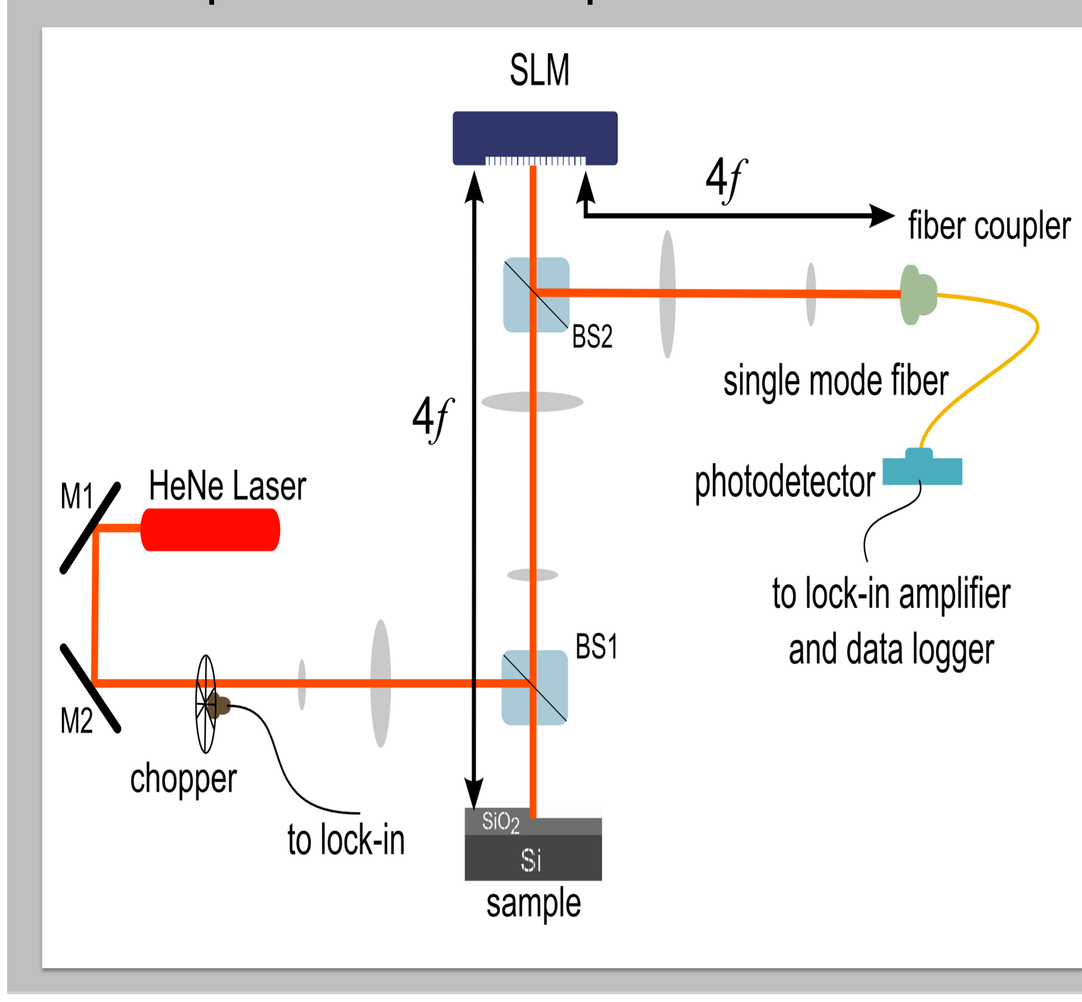
We demonstrate an optical scheme for measuring the thickness of thin nanolayers with the use of light beam´s spatial modes. The novelty in our scheme is the projection of the beam reflected by the sample onto a properly-tailored spatial mode. In the experiment described below, we are able to measure a step height smaller than 10 nm, i.e., one-eightieth (1/80) of the wavelength with a standard error in the picometer scale. The extension of this technique to the detection of subnanometric layer thicknesses is feasible.

INTRODUCTION

The search for new optical methods to measure thickness in the range of a few hundred picometers is a topic of great interest. This is driven not only by the stringent requirements of nanofabrication but also to complement and/or substitute some well-established techniques such as X-ray spectroscopy, atomic force microscopy, interferometry and ellipsometry.

In this work, we put forward a novel way to analyze layer thickness by measuring the shape of the light reflected from the sample under investigation. The key point of our approach is to project the reflected light onto a convenient ensemble of spatial modes (spatial mode projection) which are determined by some a priori available information about the sample.

The experimental setup



A HeNe laser beam impinges perpendicularly to the sample. The reflection from the sample is then projected onto an SLM where a desired phase is encoded. The resulting beam is sent to a single mode fiber. A lockin amplifier with a chopper is used to lessen technical noise.

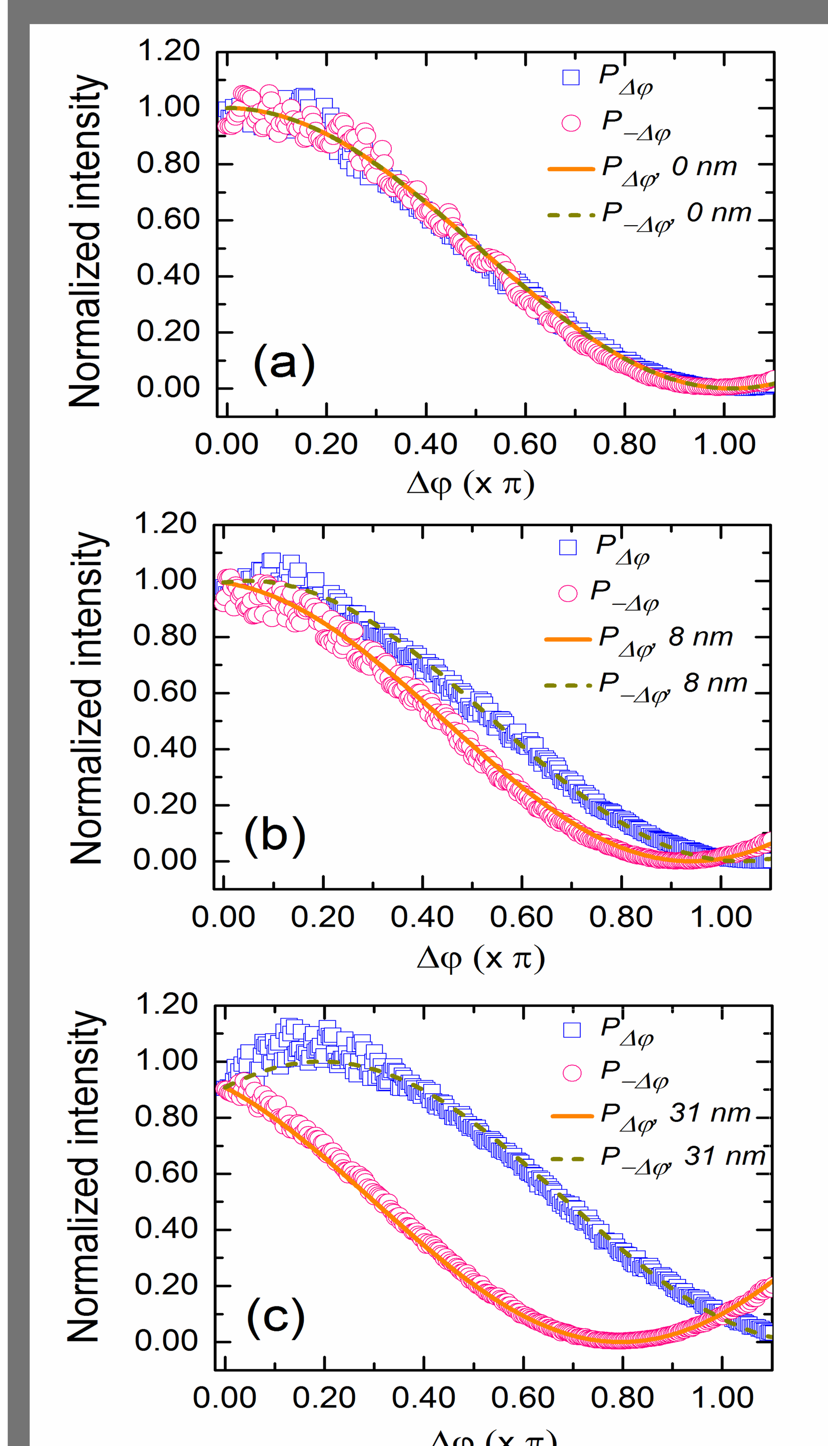
In our proof of concept experiments, we used a step sample and we projected onto a mode given by

$$U(x,y) \propto \exp\left(-\frac{x^2+y^2}{w_0^2}\right) \qquad x \le 0$$

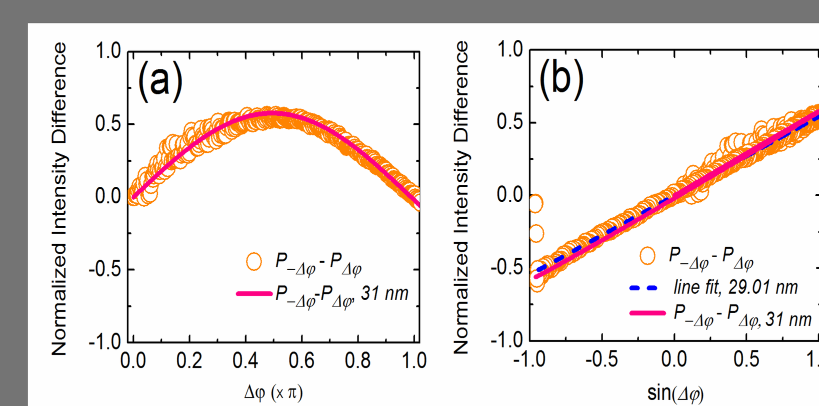
$$U(x,y) \propto \exp\left(-\frac{x^2+y^2}{w_0^2}\right)\exp(i\Delta\varphi) \qquad x > 0$$

where $\Delta\varphi$ is the phase between the two regions of the beam.

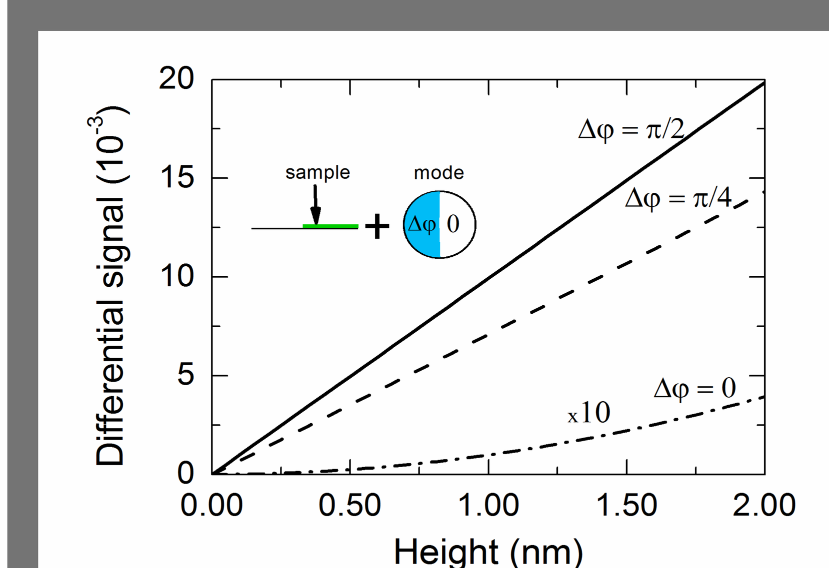
RESULTS



Normalized intensities when projected onto a mode of phases Δφ and -Δφ for different heights: (a) sample 1 (1.9 nm measured height, 0 nm profilometry measurement), (b) sample 2 (9.7 nm measured height, 8 nm profilometry measurement), and (c) sample 3 (29.0 nm measured height, 31 nm profilometry measurement). All mode projection measurements have standard error of 0.2



Typical data for analysis. (a) Normalized power difference as a function of Δφ. (b) The difference as a function of sin(Δφ) is linear. Line fit is from the calculated height (dashed line) and from theoretical calculations (solid line). For all plots, the theoretical curve is calculated from a step height of 31 nm which is independently measured with a profilometer.



Normalized differential signal as a function of the sample height when the reflected signal is projected onto a Gaussian mode with phase step Δφ. The solid, dash and dash-dotted (× 10) lines correspond to Δφ = π/2, π/4, 0, respectively.

CONCLUSIONS

- We have demonstrated that extremely small step heights can be measured without the need to impose stringent conditions on the substrate or the readout wavelength by using spatial mode projection.
- We have measured a layer thickness as low as 9.7 nm with a standard error of 170 pm in our experiment.
- Our scheme enhances sensitivity of detection. We calculate an signal-to-noise ratio of about 14 dB for an initial laser power of 1 mW. With this sensitivity, our scheme can also be used for subnanometric step height measurements.

REFERENCES

[1] N. Hermosa, C. Rosales-Guzmán, S. F. Pereira, and J. P. Torres, "Nanostep height measurement via spatial mode projection," Opt. Lett. 39, 299-302 (2014).

ACKNOWLEDGMENTS

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