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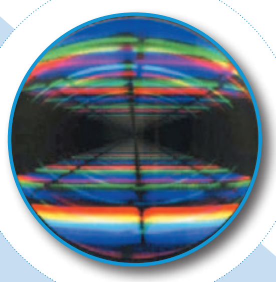
TECHNISCHE OPTIK
UNIVERSITÄT STUTTGART

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ANNUAL REPORT 2009/2010

High Resolution Metrology and Simulation

Fourier-Scatterometry for the characterization of sub-lambda periodic structures

V. Ferreras Paz, S. Peterhänsel, K. Frenner, W. Osten

As part of the of the DFG pri-ority programme SPP 1327 "Optisch erzeugte Sub-100-nm-Strukturen für biomedizinische und tech-nische Applikationen"[1] we analyse the applicability of the Fourier-Scatterometry method to characterize periodic sub-100 nm structures produced by two-photon-polymerization technique.

In recent time Fourier-Scatterometry has become of increasing interest for quantitative wafer metrology. But also in other fields the fast and precise optical characterization of periodical gratings of sub-100 nm [1] size is of great interest.

We investigated the application of Fourier-Scatterometry, extended by the use of white light for the characterization of subwavelength periodic gratings. First a simulation-based sensitivity comparison of Fourier-Scatterometry at one fixed wave-length, Fourier-Scatterometry using a white light light source and also a reference-branch for white-light-interference has been carried out. The investigated structures include gratings produced by two-photon polymerization of photosensitive material and typical semiconductor test gratings. The simulations were performed using the rigorous-coupled-wave-analysis (RCWA) included in our software package MicroSim [2]. The sample is illuminated with white light through a high-NA microscope objective (NA: 0.95) allowing an incoming illumination with wide incident (0°-72°) and azimuthal angle ranges (0°-360°). Using the full pupil illumination, Fourier-Scatterometry gives access to the complete information for every incident direction in one shot compared to fixed incident angle scatterometry equipment which has to scan over these angle ranges. The full information is contained in the backUsing white light instead of a fixed wavelength illumination gives a new dimension of freedom and finally using scanning white-light-interference allows increasing sensitivity towards structure height and shape.

The results of this sensitivity analysis show increased sensitivity towards the structure height compared with traditional Fourier-Scatterometry at one wave length and without a scanning reference-branch.

For the experimental implementation of the measurement setup we use a white light laser and a modified Leica DMR Microscope (NA 0.95) extended by an attached Linnik-type reference-branch. A scheme of the set-up can be found in Figure 1.

A comparison of measured and simulated pupil images for the combination of Fourier-Scatterometry and white-light interferometry during a scan of the reference mirror for an e-beam written resist linegrating on silicon with a line width (CD) of 200 nm and a period (pitch) of 400 nm can be found in Figures 2 and 3. The pupil images already show quite good agreement, but for actual model based recon-struction by comparing measured and simulated pupil images still some calibration has to be performed.

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Cooperation with: Nanotechnology Department at the Laser Zentrum Hannover e.V.

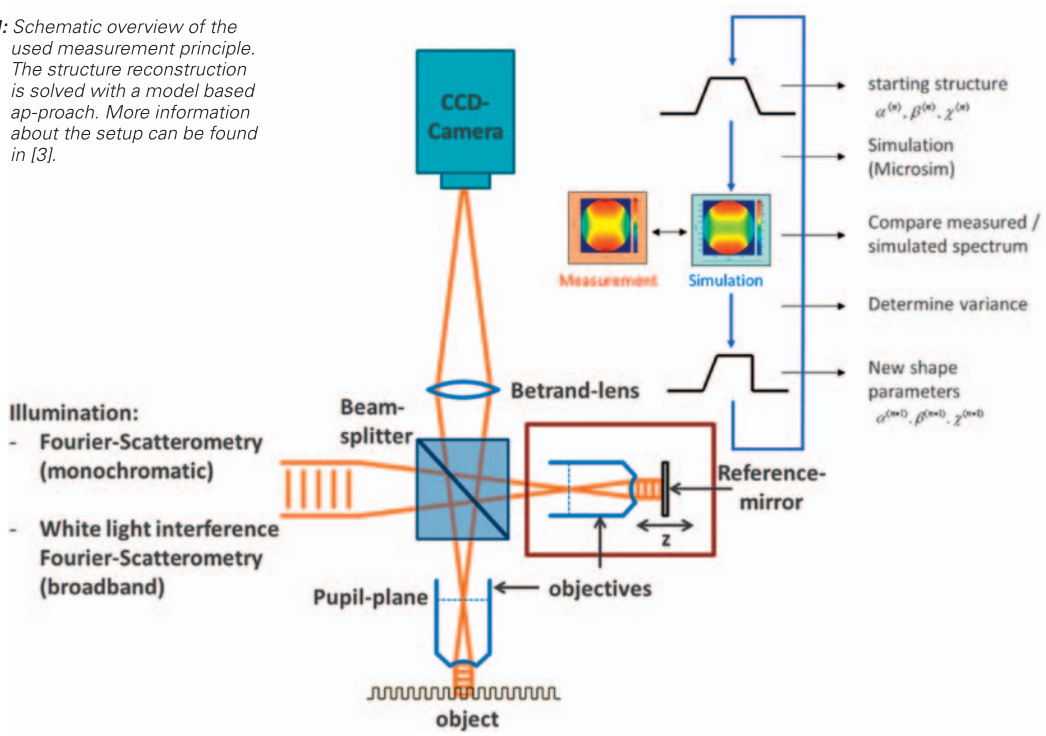
References:

[1] Osten, W.; Ferreras Paz, V.; Frenner, K.; Schuster, T. et al., "Simulations of Scatterometry Down to 22 nm Structure Sizes and Beyond with Special Emphasis on LER," AIP Conference Proceedings 1173, 371-378 (2009).

[2] Totzeck, M., "Numerical simulation of high-NA quantita-tive polarization microscopy and corresponding near-fields," Optik – International Journal for Light and Electron Optics 112, 399-406 (2001).

[3] Ferreras Paz, V.; Peterhän-sel, S.; Frenner, K.; Osten, W.; Ovsianikov, A.; Obata, K.; Chich-kov, B. "Depth sensitive Fourier-Scatterometry for the characterization of sub-100 nm periodic structures," Proceedings of SPIE 8083, 80830M-80830M-9 (2011).

Fig. 1: Schematic overview of the used measurement principle. The structure reconstruction is solved with a model based ap-proach. More information about the setup can be found in [3].



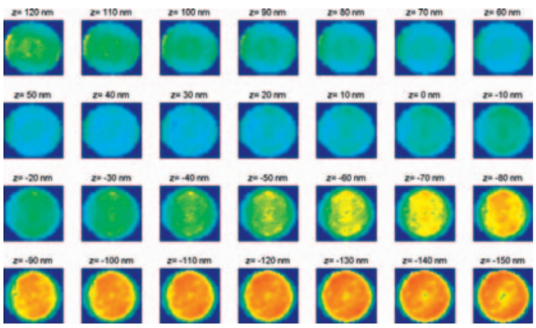


Fig. 2: Measured white-light interference Fourier-Scatterometry pupil-images (NA: 0.95, λ=400-700 nm) of an e-beam structured photoresist line-grating on silicon (CD=200 nm, Pitch=400 nm).

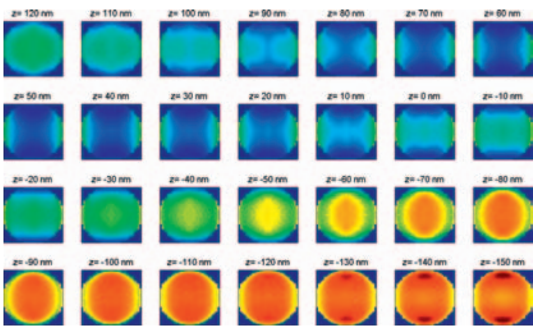


Fig. 3: Simulated white-light interference Fourier-Scatterometry pupil images (same configuration as in Fig. 2).

Inverse opto-mechanical simulation

H. Gilbergs, K. Frenner, W. Osten

The SimTech project "Optical simulation for model-based identification and suppression of static and dynamic aberrations in optics", in combination with its counterpart "Mechanical simulation …", conducted by the Institute of Engineering and Computational Mechanics, aims at an understanding of the coupling between mechanical and optical disturbances in high performance optical systems.

A common framework to support the combined simulation of mechanical and optical properties of the system has been deployed. It is based on Matlab, which controls the individual simulation modules and evaluates the results. The optical simulation is based on the commercial raytracing software Zemax, while the mechanical simulation is based on tools for multibody dynamics and finite element analysis developed at the ITM (MatMorembs and Neweul-M²).

The focus of the project lies in the identification of mechanical system disturbances from optical wavefront data. This reconstruction belongs to the group of inverse problems, which generally link an effect to its cause. Inverse problems are ill posed, which means that their solution may be not unique, continuous or even existent.

To solve this inverse problem two approaches have been investigated. The first one is a library search method, which compares the simulated outcome to a library which has been precalculated with known parameters. As the minimum size of the library, and thus the computation time for the precalculation, grows exponentially with more degrees of freedom, this method has only been applied for the tracking of single lenses with 5 degrees of freedom.

The second approach is Tikhonov regularization. Here the ill posed inverse problem is replaced by a neighboring well posed problem that delivers the most probable solution for the original problem. This approach can profit from the additional mechanical simulations as it relies on a certain amount of a-priori information on the system, which can be derived from the analysis of the mechanical properties of the system. Most notably the Eigenmodes of the system can be used as a coordinate system for the reconstruction of dynamical perturbations of the system. A frequency analysis can give a-priori knowledge on the Eigenmodes and their amplitudes for a given excitation of the system.

A reconstruction of one dimensional lateral shifts of single lenses in a lithography objective (Figure 1) from simulated wavefront data has been implemented based on Tikhonov regularization with promising results (Figure 2). The results have been presented at the "111. Jahrestagung der DGaO".

Future work will focus on a regularization based reconstruction using modal system coordinates, as well as building an experimental setup to validate the results of the simulations. Additionally development on an optical tracking method for single lenses based on total internal reflection has already started and will be carried on in the next year.

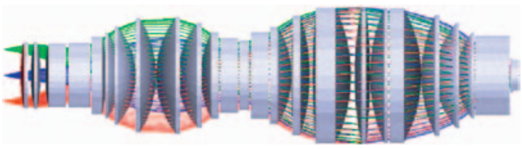


Fig. 1: *Projection lithography objective designed for an operation wavelength of 248 nm. The design is adopted from the US Patent listed in the references.*

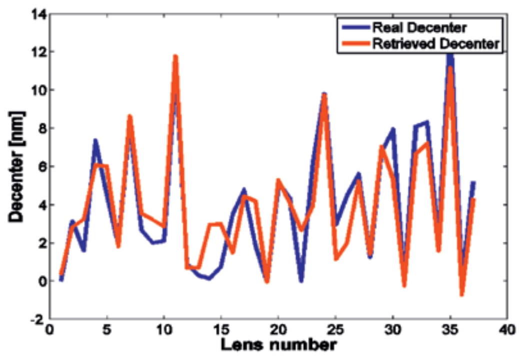


Fig. 2: *Reconstruction of 1D perturbations in the projection lithography objective depicted in Figure 1. The blue curve corresponds to the real decenter values, the red curve to the values retrieved with Tikhonov regularization.*

Supported by: DFG (EXC 310/1) "Cluster of Excellence in Simulation Technology"

References:

[1] Schuster, K. "Projection objective," US Patent US 6,522,484 B (1999).

[2] Tarantola, A. "Inverse Problem Theory and Methods for Model Parameter Estimation," siam (2005).

[3] Gilbergs, H.; Frenner, K.; E-berhard, P.; Osten, W. „Modellgestützte Rekonstruktion der Lage von dezentrierten Linsen in optischen Systemen" DGaO-Proceedings (2010).

Metamaterials for Optical and Photonic Applications in Space

P. Schau, K. Frenner, L. Fu, H. Schweizer, H. Giessen, W. Osten

Metamaterials (MTMs) are understood as metaldielectric nanostructures for light processing in the nano-scale. A specific physical feature of MTM structures is their ability to sustain coherent electron oscillations known as surface plasmon polaritons (SPPs), which confine electromagnetic energy to much smaller mode volumes than in the case of photon modes. It turns out that the interaction of these SPPs in metamaterial structures represents the basis of all metamaterial functionalities just as the exchange interaction of electrons do in solids. Moreover, the tight confinement of SPPs on metallo-dielectric interfaces is the basis of ultra-high photonic/plasmonic integration. The high energy confinement of SPPs enables the further miniaturization (integration) of optical components (waveguides and devices) to size dimensions comparable to electronic integration. A factor of 100 and better below standard optical integration density appears possible due to the large wave vectors of SPP-excitations.

Devices and networks realized with such plasmonic metamaterials provide in principle the same functionality as conventional electronic and photonic elements and networks have today. In cooperation with the 4th Physics Institute, we identified the main fields metrology, optical data processing devices and coatings, and propose novel structures for each of them.

In the field of metrology for instance, plasmonic metamaterials with magnification properties are particularly interesting. Two promising approaches are metamaterial structures with hyperbolic dispersion (Fig. 1) and metamaterials on the basis of (non-periodic) meander stacks.

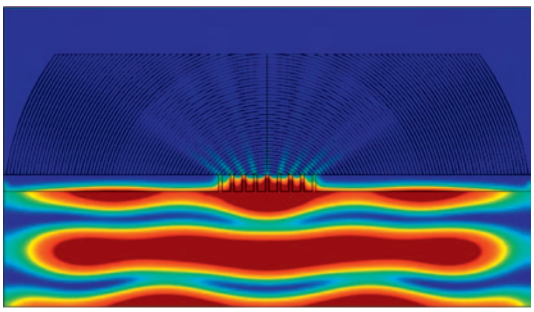


Fig. 1: *Metamaterial consisting of stacked, curved metal-dielectric layers with hyperbolic dispersion.*

The field of optical data processing devices is most promising for ultradense integrated circuits, eventually leading to an all-plasmonic nanoprocessing of light. Furthermore, spectacular properties of plasmonic structures can be demonstrated for filtering and polarization beam splitters, which can consist of only a few meander layer structures (Fig. 2). The use of slow light media can drastically improve the precision of interferometer devices and optical image processing devices.

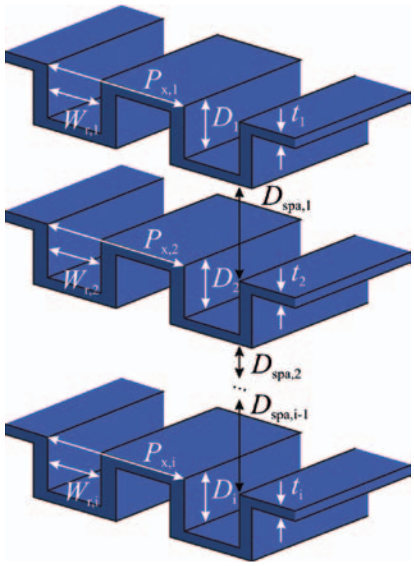


Fig. 2: *Meander stack feasible for various applications in space such as polarization beam splitters, color filters or imaging devices.*

As for coatings, a perfect absorber layer made of a metamaterial can be useful in optical instruments as well as in optical data processing circuits to suppress unwanted crosstalk by scattered light. The realization of this function by plasmonic metamaterials requires only the combination of two layers.

In all these fields, the intrinsic properties of plasmonic metamaterials meet general device and material requirements for applications in space. They are well-known as having low weight, intrinsically high radiation stability, high functionality of devices and ultra-high integration density potential.

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Metallic Meander Structures and their Potential for Sub-Wavelength Imaging

P. Schau, K. Frenner, L. Fu, H. Schweizer, H. Giessen, W. Osten

Especially in the fields of semiconductor manufacturing and nanotechnology, imaging with a very high resolution is crucial for process control and quality control measurements. At this point there exist specialized tools to perform high-resolution imaging or metrology for each process step along the fabrication chain. While demands of the industry have driven technology to the limits, none of the pre-sented solutions is capable to image arbitrary sub-lambda structures directly in a contactless, fast and non-destructive way.

This is where the new field of metamaterials can come into play. Metamaterials consist of periodic structures with dimensions smaller than the wavelength and can be designed to create particular electromagnetic responses that don't exist in nature. Particularly interesting is the Veselago material that exhibits a negative refractive index and can be used for superlensing as investigated by Pendry in 2000. Although a simple slab of silver already creates a perfect image of a sub-wavelength source, the image is still in the near-field and non-magnified. Hence, all sub-wavelength information will still decay exponentially and vanish in the far field. Our research goal is the design of a superlens capable of transforming evanescent waves to propagating modes, which then can be imaged via conventional microscopy (see below).

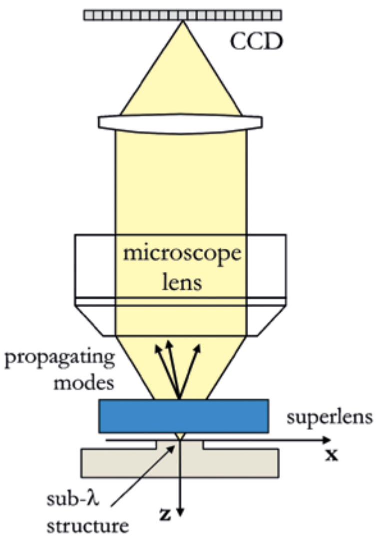

Fig. 1: *Basic setup for a superlens attached to a conventional microscope to enable sub-wavelength imaging.*

It has been shown that surface plasmon polaritons (SPPs) propagating on the metal/dielectric interfaces of a bulk negative index material (NIM) have a dominant influence on the unique properties of these materials. Consequently, one could replace bulk NIMs by resonantly coupled surfaces that allow the propagation of SPPs.

A metallic meander structure (Fig. 2) is perfectly suited as such a resonant surface due to the tunability of the short range SPP (SRSPP) and long range SPP (LRSPP) frequencies by means of geometrical variation.

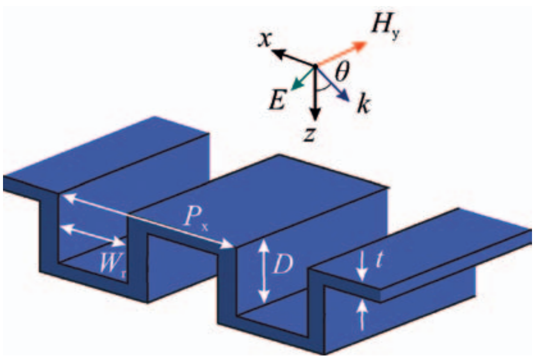

Fig. 2: *Meander structure.*

We demonstrated numerically how a stack consisting of two meander structures can mimic perfect imaging known from Pendry's lens (Fig. 3).

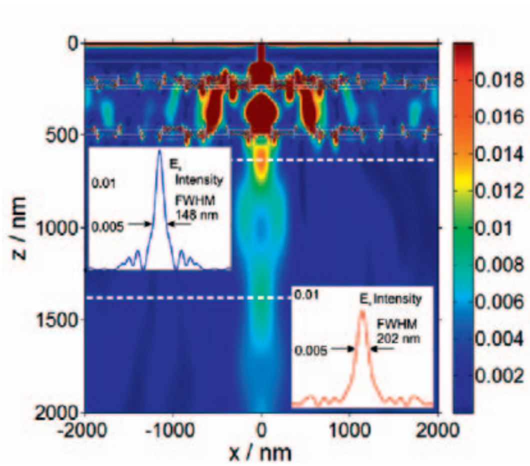

Fig. 3: *A stack of two meander structures enabling near-field imaging similar to Pendry's perfect lens.*

On the other hand, to observe sub-wavelength features in the far-field more than (perfect) near-field imaging is necessary. We are investigating stacks of meander structures with successively increasing periodicity capable to decrease the lateral wave vector until near-field to far-field transformation is achieved.

Supported by: Baden-Württemberg Stiftung
Project: "OPTIM"

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