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Fabrication influences on a miniaturised stokes polarimeter consisting of stacked nano-optical wire grid polarizer and retarders

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Abstract. The polarization properties of light can be fully controlled with nano-optical wire grid polarizers and artificial birefringent grating structures. We demonstrate an integrated polarimeter based on stacked layers of such elements. However, the optical performance of such elements is fundamentally limited and may be further altered by deviations arising from the fabrication processes. In this contribution we investigate the influences on the polarimetry performance for such a device.

1 Introduction

Nowadays optics technology is an important driving force in many aspects of our everyday life. Highly developed optical systems are enabling self-driving cars [1,2], high-resolution images with smartphone cameras and advanced medical services [3,4]. To achieve that, modern fabrication technology strives to ever smaller and more demanding structures. This is only achievable by closed loop process control. While many solutions are existing for that purpose, often elaborate equipment is required. As an example, ellipsometry can be utilized to retrieve information about thickness and refractive index of a deposited thin film [5]. While the achievable results are excellent with very small uncertainties, the required devices are large and expensive. By more sophisticated devices, it is even possible to deduce detailed information about the geometry of nanostructures [6]. Unfortunately, the size of such tools reduces their application range drastically. We propose a miniaturized polarimeter consisting of pixelated and stacked polarizer and retarder structures on an image sensor.

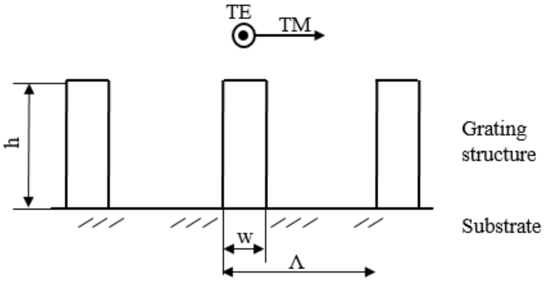

Fig. 1. Schematic grating structure for polarisation control. Direction for TE and TM polarized light is marked.

Zero-order grating structures (see Fig. 1) can be utilized to control the polarisation state of light. For this purpose, the grating period must be sufficiently small, such that only the zeroth diffraction order is transmitted. Depending on the utilized material either artificial birefringence or di-attenuation can be observed. For an absorbing grating material an exponential damping occurs for TE polarized light (TE-transversal electric, electric field vector parallel to ridges) while TM-polarized light is mostly transmitted [7]. Hence, the transmittance of such structures strongly depend on the polarisation direction, so that these elements can be used as linear polarizers (LP). If the grating material is dielectric the effective refractive index depends on the polarisation direction, hence such structures can be used as quarter wave plates (QWP) [8].

In order to measure the Stokes parameter of incident light a QWP and a LP are typically utilized. Classically, four (or six) subsequent measurements at different rotation angles of the linear polarizer, with and without the quarter wave plate, are performed to deduce the full set of stokes parameters[9]. In the here shown concept the LP and QWP are stacked in different layers of the optical element on a microscopic scale. Since the structures are fabricated by lithography, their direction can be locally changed (see Fig. 2). Thereby, multiple channels can be achieved on an image sensor. Combining the information of all channels, the stokes parameters can be evaluated.

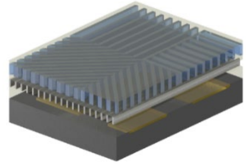

Fig. 2. Schematic of an integrated Stokes polarimeter consisting of a (top to bottom) birefringent grating as QWP, wire grid polarizer as LP and an image sensor.

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In Fig. 3, an SEM image of a cross section of one pixel of such a stacked nano-optical device is shown. The lower grating layer is the QWP structure consisting of titanium dioxide [8,10]. The upper layer is the LP structure consisting of iridium [11]. The intermediate layer is fabricated by filling the underlying grating with a sacrificial polymer and over coating of porous silicon oxide [12,13]. The sacrificial layer is removed by oxygen plasma ashing, creating a void in between the grating ridges. Thereby a high refractive index contrast is achieved. The wire grid polarizer is capped by over coating with ion beam deposition under an oblique angle.

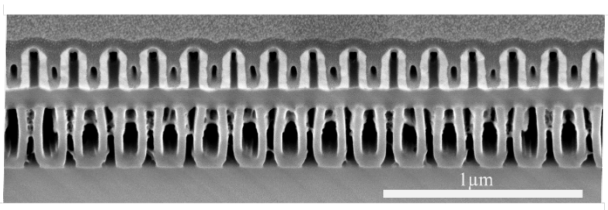

Fig. 3. Cross sectional SEM image of a layered grating structure. The upper layer consists of Ir and serves as linear polarizer, the lower layer consists of titanium dioxide and serves as retarder.

Typically the optical performance achievable with such nano-optical elements is limited compared to their classical counterparts [14,15]. That means the phase of the QWP may deviate from the ideal value and the extinction ratio (ratio between transmittance for TE and TM polarized light) of the LP is limited to values <1000 [16]. In this contribution we investigate the influence of these deviations on the optical performance of such a Stokes polarimetry by rigorous coupled wave analysis, Monte Carlo simulations and ray tracing. Furthermore, we propose advanced designs exploiting the unique possibilities available due to the lithographic fabrication techniques.

2 Conclusion

Nano-optical wire grid polarizers and retarders allow the full control of the polarization properties of light. Furthermore, since these elements are fabricated by lithography, they can be arranged on an image sensor in a pixelated manner. Thereby, multiple polarization channels are achieved enabling the single-shot evaluation of the Stokes parameter of incident light. However, the optical performance of such elements is limited. In this contribution, we investigate the influence on the performance to miniaturised polarimetry.

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References

1. C. Häne, L. Heng, G. H. Lee, F. Fraundorfer, P. Furgale, T. Sattler, and M. Pollefeys, "3D visual perception for self-driving cars using a multi-camera system: Calibration, mapping, localization, and obstacle detection," Image Vis. Comput. **68**, 14–27 (2017).
2. C. Badue, R. Guidolini, R. V. Carneiro, P. Azevedo, V. B. Cardoso, A. Forechi, L. Jesus, R. Berriel, T. M. Paixão, F. Mutz, L. de Paula Veronese, T. Oliveira-Santos, and A. F. De Souza, "Self-driving cars: A survey," Expert Syst. Appl. **165**, 113816 (2021).
3. D. Qiao, F. Zulkernine, R. Masroor, R. Rasool, and N. Jaffar, "Measuring Heart Rate and Heart Rate Variability with Smartphone Camera," Proc. - IEEE Int. Conf. Mob. Data Manag. **2021-June**, 248–249 (2021).
4. K. Kaur, W. Chelangat, S. I. Druzhinin, N. W. Karuri, M. Müller, and H. Schönherr, "Quantitative E. coli Enzyme Detection in Reporter Hydrogel-Coated Paper Using a Smartphone Camera," Biosens. 2021, Vol. 11, Page 25 **11**(1), 25 (2021).
5. A. Gottwald, K. Wiese, T. Siefke, and M. Richter, "Validation of thin film TiO <inf>2</inf> optical constants by reflectometry and ellipsometry in the VUV spectral range," Meas. Sci. Technol. **30**(4), (2019).
6. T. Käseberg, J. DIckmann, T. Siefke, M. Wurm, S. Kroker, and B. Bodermann, "Mueller matrix ellipsometry for enhanced optical form metrology of sub-lambda structures," in *Proceedings of SPIE - The International Society for Optical Engineering* (2019), **11057**.
7. T. Siefke, E.-B. Kley, A. Tünnermann, and S. Kroker, "Design and fabrication of titanium dioxide wire grid polarizer for the far ultraviolet spectral range," in *Proceedings of SPIE - The International Society for Optical Engineering* (2016), **9927**.
8. C. Stock, T. Siefke, and U. Zeitner, "Metasurface-based patterned wave plates for VIS applications," J. Opt. Soc. Am. B **36**(5), D97 (2019).
9. A. Forbes, A. Dudley, K. Singh, and N. Tabebordbar, "Digital Stokes polarimetry and its application to structured light: tutorial," JOSA A, Vol. 37, Issue 11, pp. C33-C44 **37**(11), C33–C44 (2020).
10. T. Siefke, S. Kroker, K. Pfeiffer, O. Puffky, K. Dietrich, D. Franta, I. Ohlídal, A. Szeghalmi, E. Kley, and A. Tünnermann, "Materials Pushing the Application Limits of Wire Grid Polarizers further into the Deep Ultraviolet Spectral Range," Adv. Opt. Mater. **4**, 1780–1786 (2016).
11. T. Weber, T. Käsebier, A. Szeghalmi, M. Knez, E.-B. Kley, and A. Tünnermann, "Iridium wire grid polarizer fabricated using atomic layer deposition," Nanoscale Res. Lett. **6**(1), 558 (2011).
12. L. Ghazaryan, E.-B. Kley, A. Tünnermann, and A. Szeghalmi, "Nanoporous SiO_2 made by atomic layer deposition and atomic layer etching," Nanotechnology **27**(25), 96270P (2015).
13. "DE102016100907A1 - Verfahren zur Herstellung eines reflexionsmindernden Schichtsystems und reflexionsminderndes Schichtsystem - Google Patents," https://patents.google.com/patent/DE102016100907A1/fr.
14. T. Siefke, M. Heusinger, C. B. R. Hurtado, J. Dickmann, U. Zeitner, A. Tünnermann, and S. Kroker, "Line-edge roughness as a challenge for high-performance wire grid polarizers in the far ultraviolet and beyond," Opt. Express **26**(15), 19534 (2018).
15. T. Siefke, D. Lehr, T. Weber, D. Voigt, E.-B. Kley, and A. Tünnermann, "Fabrication influences on deep-ultraviolet tungsten wire grid polarizers manufactured by double patterning," Opt. Lett. **39**(22), (2014).
16. T. Siefke and S. Kroker, "Polarization Control by Deep Ultra Violet Wire Grid Polarizers," in *Optical Chaacterization of Thin Solid Films*, O. Stenzel and M. Ohlidal, eds. (Springer, 2018), pp. 359–374.