DOI 10.5162/iCCC2026/5.3

Entwicklung von Plasmonischen On-Chip Sensoren

Development of Plasmonic On-Chip Sensors

Sebastian Reiter, Brandenburgische Technische Universität Cottbus-Senftenberg, Cottbus, reiter@b-tu.de
Akant Sengül, Brandenburgische Technische Universität Cottbus-Senftenberg, Cottbus, Germany, akant.senguel@b-tu.de
Paul-Gregor Nitsch, Brandenburgische Technische Universität Cottbus-Senftenberg, Cottbus, Germany, Paul-Gregor.Nitsch@b-tu.de
Fritz Berkmann, Brandenburgische Technische Universität Cottbus-Senftenberg, Cottbus, Germany, fritz.berkmann@b-tu.de
Carlos Alvarado Chavarin, IHP - Leibniz-Institut für innovative Mikroelektronik, Frankfurt Oder, Germany, alvarado@ihp-microelectronics.com
Jon Schlipf, IHP - Leibniz-Institut für innovative Mikroelektronik, Frankfurt Oder, Germany, schlipf@ihp-microelectronics.com
Christian Mai, IHP - Leibniz-Institut für innovative Mikroelektronik, Frankfurt Oder, Germany, cmai@ihp-microelectronics.com
Christian Wenger, IHP - Leibniz-Institut für innovative Mikroelektronik, Frankfurt Oder, Germany, wenger@ihp-microelectronics.com
Inga Anita Fischer, Brandenburgische Technische Universität, Cottbus, Germany, fischeri@b-tu.de

Kurzfassung

Diese Arbeit präsentiert die Entwicklung eines plasmonischen On-Chip Sensors, der als hochsensitiver Brechungsindexsensor für biosensorische Anwendungen konzipiert wurde. Der Sensor integriert ein plasmonisches Titannitrid (TiN) Nanolochgitter (NHA) mit einem Germanium (Ge) Photodetektor. Die optische Transmission durch das NHA wird überwiegend durch plasmonische Anregungen bestimmt und zeigt eine außergewöhnliche optische Transmission (EOT). Diese Resonanzen reagieren äußerst empfindlich auf Änderungen des Brechungsindexes der umgebenden Medien.

Abstract

This work presents the development of a plasmonic on-chip sensor as a highly sensitive refractive index sensor for biosensing applications. The device integrates a plasmonic titanium nitride (TiN) nanohole array (NHA) with a germanium (Ge) photodetector. The optical transmission through the NHA is predominantly determined by plasmonic excitations and exhibits extraordinary optical transmission (EOT). These resonances are highly sensitive to variations in the refractive index of the surrounding medium.

1 Introduction

There is a growing need for miniaturized on-chip optical sensors, which can be utilized, e.g., for biosensing in diverse fields such as agriculture, environmental diagnostics and healthcare. Here, we present recent results on a plasmonic sensor concept for applications in refractive index sensing. Our device is fabricated on a 200 mm Si platform, enabling both cost-effective realization and a high degree of reproducibility. We report on experimental sensor characterization and sensing performance, compare to simulation and discuss possible further applications of our devices.

2 Refractive Index Sensor

Optical properties of plasmonic resonances such as propagating surface plasmon polaritons at the interface between a metal and a dielectric or localized surface plasmon resonances in metallic nanoparticles sensitively depend on the refractive index of the surrounding dielectric medium. This has applications in refractive index sensing, however, commercialized sensors based on plasmonic excitations rely on bulky equipment such as microscopes or spectrometers for readout. Here, with the aim of miniaturizing this approach, we present an on-chip solution consisting of a plasmonic nanohole array as sensing element, whose optical properties change when exposed to dielectrics with different refractive indices, in combination with a Ge-photodetector that serves as a transducer [1] and converts the optical signal directly into a photocurrent. A schematic drawing of the device is presented in Figure 1.

DOI 10.5162/iCCC2026/5.3

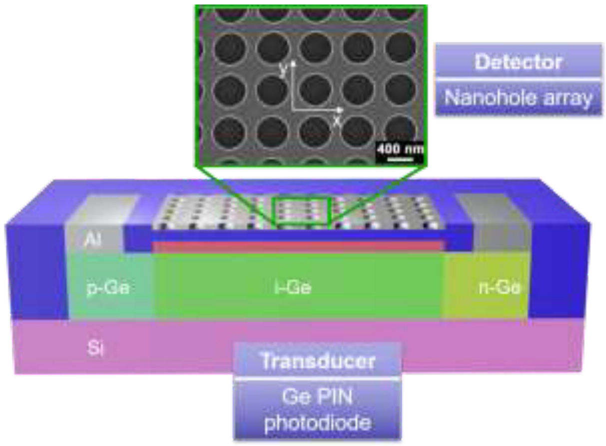

Figure 1 Schematic drawing of the concept of a plasmonic on-chip refractive index sensor consisting of a plasmonic TiN NHA and da Ge photodetector.

Compared to the realization of a proof-of-concept device [1], transitioning the device concept to large-scale production necessitates modifications for compatibility with CMOS manufacturing processes, introducing additional constraints in material choices, fabrication and design [2,3]. Our sensor can be fabricated using standard industrial complementary metal-oxide-semiconductor (CMOS) fabrication processes [2,3], enabling cost-efficient, high-yield production. In our devices, TiN as a CMOS-compatible metal is used for the fabrication instead of the more widely used Au and Ag.

2.1 Results and Discussion

Surface plasmon polaritons (SPPs) can be excited by illumination of the NHA, which enables momentum matching between the incident photons and the SPPs through the reciprocal lattice vectors of the periodic structure. This leads to EOT, which occurs as asymmetric resonance peaks known as Fano-resonances [3-5]. These resonances are highly sensitive to changes of the refractive index in the proximity of the NHA (Fig. 2).

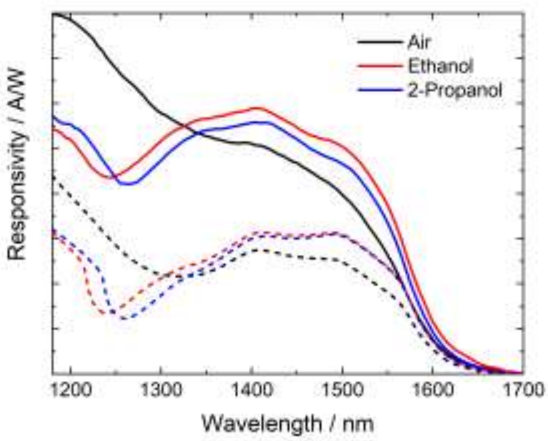

Figure 2 Responsivity spectrum of on-chip refractive index sensor immerged in ethanol (red) and 2-Propanol (blue).

In our experimental setup, shifts of the resonance dip are induced by altering the refractive index of the surrounding medium, notably, by immersing the sensor in ethanol (red) and 2-propanol (blue). The measured results (solid lines) compared to the simulated results (dashed lines) indicate a very high qualitative agreement and demonstrate the operability of the sensor concept. The difference between simulation and experiment results from the illumination conditions, which allow scattered light to enter the photodetector without passing through the nanohole array. The sensitivity to bulk refractive index changes, defined as the shift in resonance wavelength divided by the change in refractive index (RI), was measured to be ~900 nm/RIU in our sensors. This is confirmed by FDTD simulations.

3 Conclusion

Our results indicate that integrating NHAs with Ge photodetectors is an interesting approach for on-chip RI sensing. The integration of the NHA into a Ge-photodetector enables the use of the generated photocurrent as the output signal of the device. As a result of comparatively large damping in TiN, resonances in our NHAs are broad. Various strategies exist and are being implemented by us to improve the resonance shape while leaving the sensitivity unaffected. These comprise geometry changes (generation of quasi-BICs by changing the shape of the nanoholes) and material changes (deposition of a thin layer of Au in a post-CMOS deposition step). Furthermore, the presence of optical resonances in the responsivity spectra of our devices also have potential applications in on-chip spectrometers. Our work, thus, represents an important step in the development of cost-efficient on-chip sensors on the silicon platform.

4 Acknowledgements

This work was funded by Germany's Federal Ministry of Research, Technology and Space (BMFTR) under grant numbers: 16ES1128K, 16ME0420K, 16ES1131 16ME0424. The authors gratefully acknowledge the computing time granted through the North-German Supercomputing Alliance (HLRN) and provided on the supercomputing system. This work was supported by HLRN project ID bbp00044.

5 Literature

[1] L. Augel, Y. Kawaguchi, S. Bechler, R. Körner, J. Schulze, H. Uchida, and I. A. Fischer, "Integrated Collinear Refractive Index Sensor with Ge PIN Photodiodes," ACS Photonics **5**(11), 4586–4593 (2018).

[2] C. Mai, S. Marschmeyer, A. Peczek, A. Kroh, J. Jose, S. Reiter, I. Fischer, C. Wenger, and A. Mai, "Integration Aspects of Plasmonic TiN-based Nano-Hole-Arrays on Ge Photodetectorsin a

200mm Wafer CMOS Compatible Silicon Technology," ECS Transactions **109**, 35–46 (2022).

[3] C. Mai, A. Peczek, A. Kroh, J. Jose, S. Reiter, C. Wenger, and I. A. Fischer, "Towards a CMOS compatible refractive index sensor: cointegration of TiN nanohole arrays and Ge photodetectors in a 200 mm wafer silicon technology," Optics Express **32**(17), 29099–29111 (2024).

[4] S. Reiter, W. Han, C. Mai, D. Spirito, J. Jose, M. Zöllner, O. Fursenko, M. A. Schubert, I. Stemmler, C. Wenger, and I. A. Fischer, "Titanium Nitride Plasmonic Nanohole Arrays for CMOS-Compatible Integrated Refractive Index Sensing: Influence of Layer Thickness on Optical Properties," Plasmonics **18**(3), 831–843 (2023).

[5] S. Reiter, M. Ratzke, P.-G. Nitsch, C. Mai, D. Spirito, A. A. Corley-Wiciak, C. Wenger, and I. A. Fischer, "Optical Response of Titanium Nitride Plasmonic Nanohole Arrays: Impact of Square and Hexagonal Array Geometry, Pitch, and Nanohole Diameter," Plasmonics (2025).