Super-Resolution Optical Microscopy for Investigations of Defects in Semiconductor Device

Nagendra Prasad Yadav (nagendra1nagendra@gmail.com)
Hubei Polytechnic University https://orcid.org/0000-0001-8932-4607
Guozhen Hu
Hubei Polytechnic University Huangshi China
Zhengpeng Yao
Hubei Polytechnic University Huangshi China

Research Article

Keywords: Polarization, Light scattering, Optical Diffraction Limit, Semiconductor, Nanoscale Microscopy

Posted Date: June 28th, 2021

DOI: https://doi.org/10.21203/rs.3.rs-565309/v1

Super-Resolution Optical Microscopy for Investigations of Defects in Semiconductor Device

Nagendra P. Yadav[1], Guozhen Hu[1] and Zhengpeng Yao[1]
[1]School of Electrical and Electronics Information Engineering, Hubei Polytechnic University, NO.16 North Guilin Road, Huangshi, Hubei, China
Email: *Corresponding authors npycn@ieee.org huguozhen@hbpu.edu.cn

Abstract:

Ripples scattering of sidewall in pattern devices is efficient and necessary for monitoring the semiconductor fabrication process. As a step towards improving the imaging quality in terms of scattering, an attempt has been made to use our recently reported method called Parametric Indirect Microscopic Imaging (PIMI) for the thin layer of pattern devices. The present study demonstrates that the resolving power of PIMI imaging for the sidewall of the pattern devices is better than that of the conventional microscopy techniques. The better resolving power of the present PIMI technique for imaging the sidewalls paves the (new) way for its industrial application for the inspection of the integrated semiconductor circuits. For the demonstration, PIMI images have been compared with AFM, which are very close agreement.

Keywords: Polarization; Light scattering; Optical Diffraction Limit; Semiconductor; Nanoscale Microscopy.

Introductions:

Gallium nitride (GaN) based semiconductor pattern devices have garnered much attention in recent years due to their attractive optical and electrical properties [1]. Low-cost and high-resolving power optical microscope is needed in wide-field scattered imaging for industrial applications [2]. We have proposed and developed a new type of microscope based on a polarization technique, which is termed ‘parametric indirect microscope imaging (PIMI) [3]. The sidewall of the pattern devices, coated with metal plays an important role in the modern semiconductor industry [4]. Due to the time imperativeness and the high demand of measurement efficiency the choice for inspection tool can only be optical microscopy with super resolution than the simple Atomic Force Microscopy (AFM) [5], which cannot be useful to carry out the inspection in the production line. The optical microscope is very easy to handle and not more expensive as compared to SEM and AFM, because both microscopes are taking more time for scanning and the imaging area is very small. Due to the optical diffraction limit, resolution that can achieve with a conventional optical microscope is intrinsically limited to approximately 200 nm in visible light. Realizing higher resolution in scattering fields especially in semiconductor and metal pattern devices, by developing new type optical microscopes has been an active area of research [6-8]. As steps towards breaking the diffraction limit, researchers have been demonstrated the optical imaging based on the structural and scattering information of the sidewall layers using optical microscope [9-10]. Recently, a technique for imaging scatterometry and two designs of scatterometers capable of measuring with nanometric accuracy over field of views up to cm^2 has been developed [11]. It has been reported that the dark field illumination can be a better option for scattering information of the sidewall [12]. Recently, we have demonstrated the use of PIMI system for the light scattering measurement of Cu_2O particle [13]. Yet another work proved the use of it for sensing the scattering signals from a sub micrometer particle [14]. Further, some of the researchers have reported the fabrication of GaN-based device structure on a nanoscale patterned silicon substrate [15]. To the best of our knowledge, this is the first time we reports the PIMI method for the characterization and resolving of the sidewall ripples in the patterned semiconductor devices. The study reports that, (PIMI) technique for the scattering of pattern based rough surfaces, pointing the ripples characteristics sidewall of the pattern devices and the same has been compared with conventional methods as well as AFM. The present method offers a new direction to get the exact information of sidewall and edges.

2. Methods and Experimental Setup:

Based on the reported theory [3] we proposed a developed polarization (PIMI) system for measure the scattering of sidewall as shown in Fig.1 (b). It consists of an Olympus reflection microscopic system BX51M, which provides the basic optical patch. We insert it into a polarization-modulation mechanics with an angle precision of 0.05°. The CCD in the system was manufactured by Basler (piA2400-17gm) with the pixel resolution of 3.45 micron and output dynamic range of 12 bits. The 3.45-micron-pixel CCD resolution results in an outmost potential resolving power of 34.5nm if the diffraction limit is broken and the Nyquist principle is fulfilled in the microscopic system, working with a *100*× objective. We used a sample of semiconductor pattern devices, look like finger patterned shown in fig.1 (a).

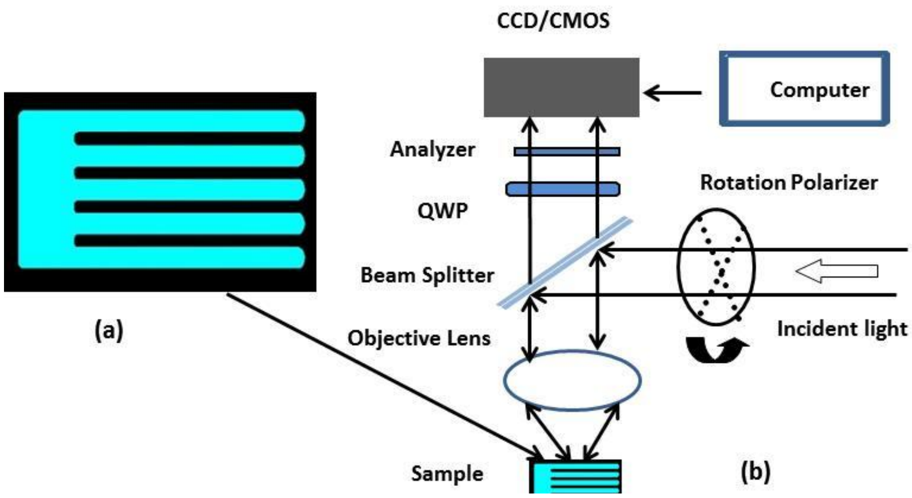

Fig.1(a) Sample cross pattern and (b) Scheme of the polarization PIMI for the measurement of the Stokes parameters (ϕ).

Sample Preparation and Description:

The sample has been made like multilayer with adopting a simple etching method. The samples have been fabricated by using the method of Buffered Oxide Etch (BOE). The process of fabrication can be described by following six steps:

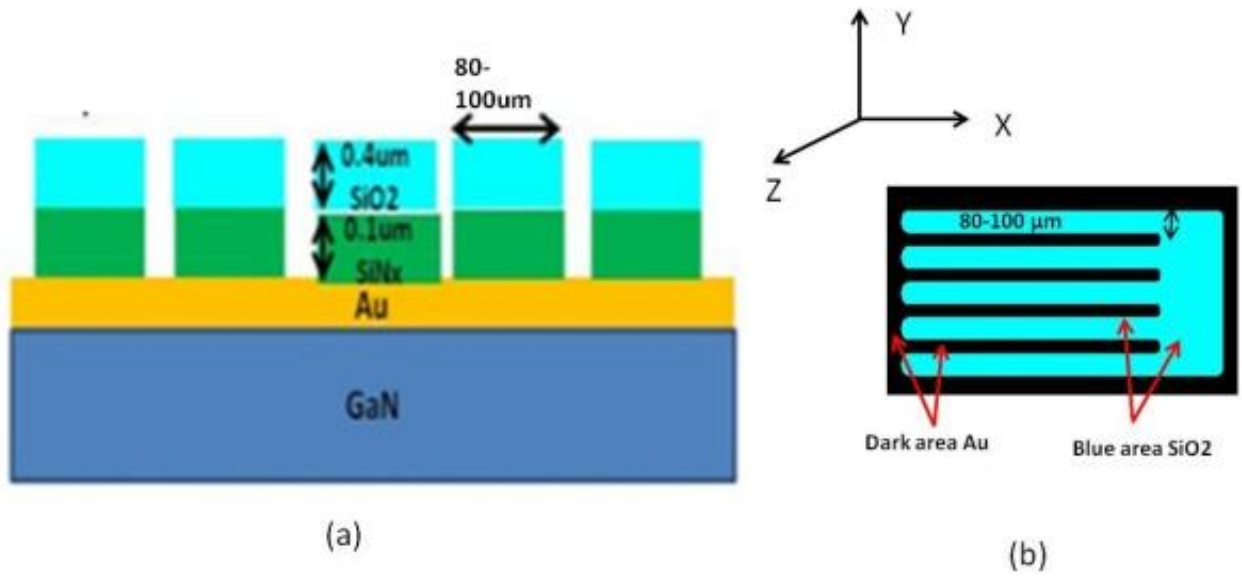

Fig.2: (a) Side view and (b) Top view geometry of the finger type pattern device of the sample.

(1) Deposition on a GaN wafer and then (2) Photoresist coating; (3) Light exposure; (4) Development of the photoresist,0.4 micrometer SiO_2 and 0.1 micrometer SiNx etching (5) Dire and removing SiNx/SiO2/Au(Mask); (6) Hydrogen annealing [11]. Basically, we have used different methods for cleaning the sample. The sample has been cleaned by using the solution of (H_2SO_4+H_2O_2) and water. The sample has to be air dry for half an hour before the experiment. One can see from Fig.2 (b), the pattern looks like five fingers. The dark area is Au and the blue area is SiO_2. The width of one finger and the gap between two fingers are between 80~100 micrometers. Thickness of each fingers are same as 0.4 micrometer SiO_2 + 0.1 micrometer SiNx. The detailed parameters have been described in Fig.2 (a).

3.Results and Discussion:

We have examined by using semiconductor sample for the information of optical characteristics of sidewall, which has been shown in Fig.3.The detailes of the sample can be seen in the Fig. 2. Figs.3(a-d), shows the results of the scattering and structural information on sidewall of the pattern devices. Fig 3 (b, c) gives the comparison between the conventional and PIMI dark field images recorded with the same optics. From the figure it is clear that the PIMI parameter ϕ resolves the structural and edge information of the sidewall in a better way than the conventional microscopic image I_{00}. The sidewall information in I_{00} image which is approximately lost, has been visualized quite clearly in ϕ image. A comparison between the I_{00} and ϕ image has been shown by plotting the data in a linear graph as can be visualized in Fig. 3(d). This data has been extracted along the line shown in Fig. 3(b, c). As expected, the shape of the intensity profile in conventional microscopy exhibit no peak, whereas within that area under the peak of the I_{00}, there can be several peaks appeared in case of the ϕ parameter image of the PIMI. Here, one can see the edge resolution of the sidewall, has been mentioned through different circle in section (d) of Fig.3. At this point the optical anisotropy is very strong due to change of polarization status because of fresnel reflection. For the demonstration of above PIMI results, we have compared with the AFM results, which can be seen in fig.4. Form fig. 4, one can see the difference between AFM and PIMI images. As proposed, the shape of the intensity profile in AFM exhibit no peak fig.4 (d), whereas, there can be two peaks appeared in the case of the ϕ parameter image of the PIMI by extracting the data with the help of an insertion of line on both the images (Figs. 4 c, e). It can be seen a huge difference in the images of the AFM and the PIMI system regarding resolving features of the SUT. The full width at half-maximum (FWHM) in the intensity line profile plot of PIMI is about 50 nm. The structural information of sidewall from the same position has been extracted from images provided by AFM and PIMI shown in Figs.4 (a)-(b). The edge of sidewall features has been shown in PIMI image, PIMI resolves the inner sidewall features of SUT, which are not clear in the AFM, can be compared with a line graph drawn in fig.4 (d).There are many physical features can be seen in PIMI image indicated by different places which are very close to AFM image, shown in fig.4 (a-b).These results proved a remarkable resolving power of the PIMI system.

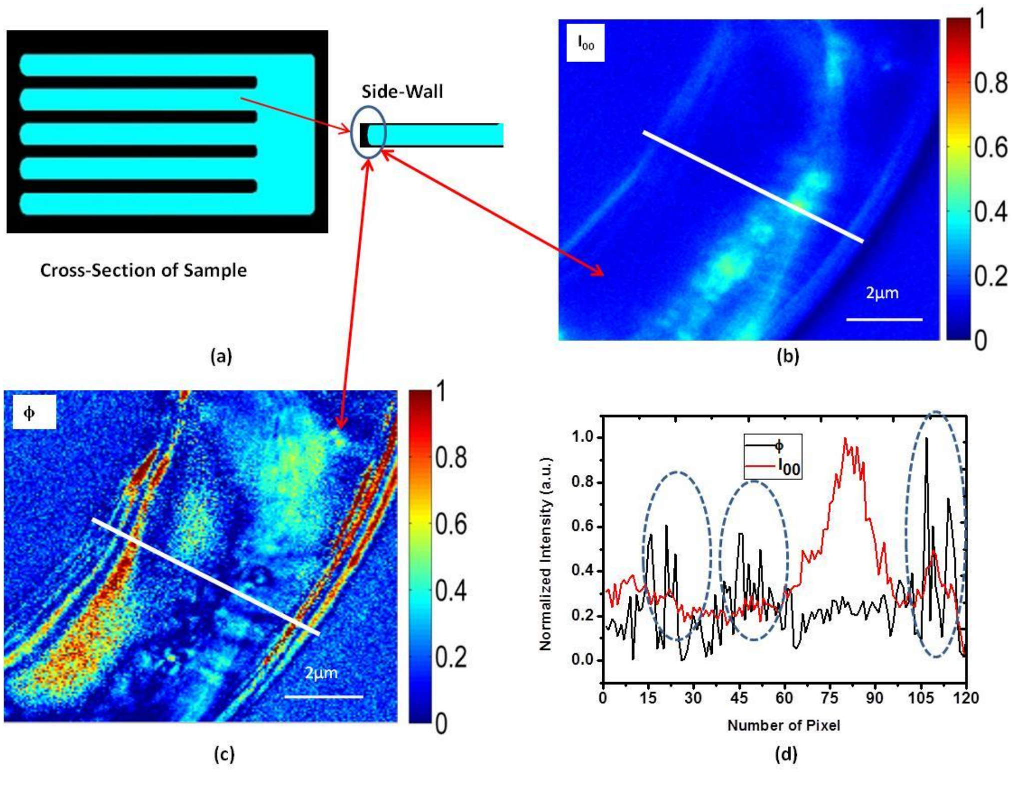

Fig.3(a).Cross-Sectional geometry of semiconductor integrated pattern (sample), (b) information of scattering and nanocharacteristics on side-walls by using cross a line in image taken by conventional (I_{00}) at

50×magnification and (c) same information collected by image taken by PIMI parameter ϕ at 50× magnification, (d) variation between number of pixel and normalized intensity with help of data collected by conventional and PIMI image. The colour scale for orientation is shown on the right-hand side of each image.

4.Conclusion:

In summary, the present method demonstrates a new optical approach to measure sub-wavelength features of sidewall (Scattering of Semiconductor Pattern Surface) with PIMI, which have wide-range of applications in nanotechnology. The study uses dark field images of the integrated semiconductor samples. Due to illumination angle, the nanolayers in sidewall of the pattern devices have been recognized by our system, which was not possible by conventional imaging system. The superior nature of the PIMI technique in resolving the edge information and scattering of the sidewall with sub-wavelength information which lacked by the conventional microscopy, compared with AFM result has been illustrated in the present work. The proposed optical system finds its application in semiconductor based electronics devices and other semiconductor manufacturing metrology devices by paving way to the new generation fabrication with high resolution imaging.

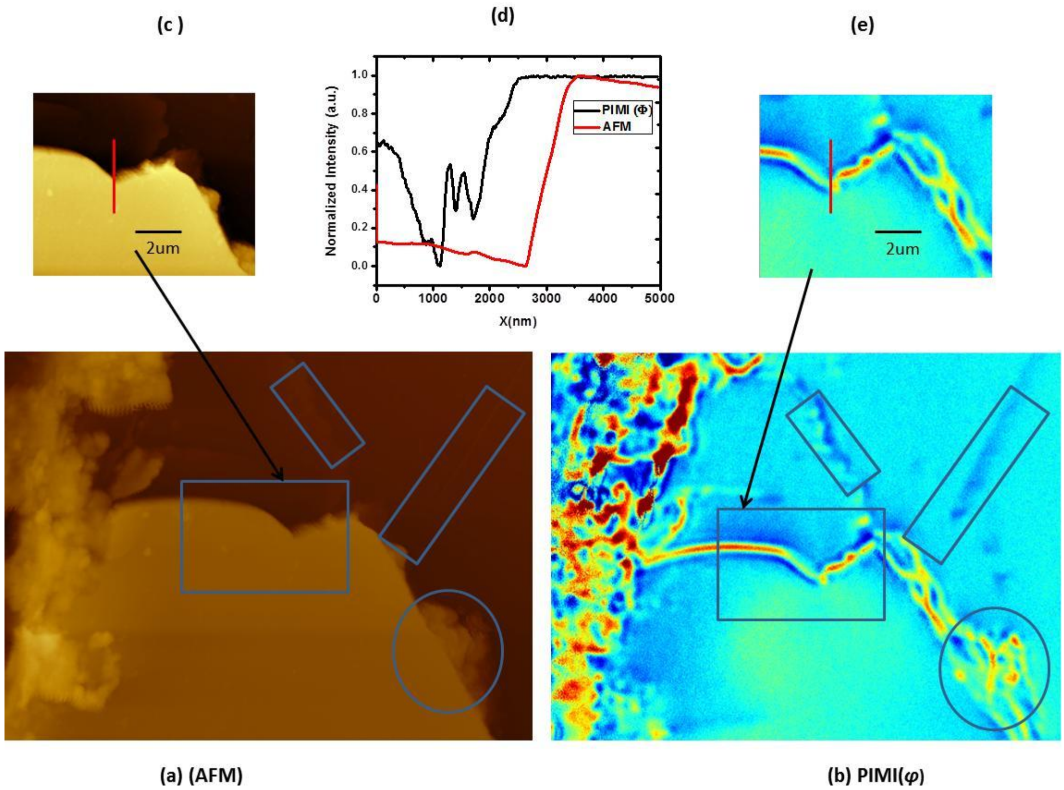

Fig.4. PIMI images of sample were taken by the 100× objective bright fields of the N.A (0.90) (b) compared with AFM image (a) and its intensity profile plotting by drawing a line in the same position of both the images (d), small part extracted from AFM and PIMI in analyzing the resolving power comparison (c, e).

5. Acknowledgement:

The authors wish to acknowledge the financial support by special project for guiding local science and technology development (2018ZYYD006) and Hubei Polytechnic University Laboratory Funds (19XJK24R).

Compliance with Ethical Standards: The authors declare that, they have no conflict of interest.

REFERENCES:

[1]. P. C. Upadhya, J. A. Martinez, Qi Li , G. T. Wang , B. S. Swartzentruber, J.A.Taylor and R. P. Prasankumar," Space-and-Time-Resolved Spectroscopy of Single GaN Nanowires,"*Appl. Phys. Lett.* 106 pp. 263103-1-5,2015.

[2]. J.B. Pawley," Handbook of Biological Confocal Microscopy," *3rd edition Springer; New York,*2006.

[3]. X. Liu, B. Qiu, Q. Chen, Z. Ni, Y. Jiang, M. Long, and L. Gui, "Characterization of graphene layers using super resolution polarization parameter indirect microscopic imaging," *Optics Express* 22, 20446-20456, 2014.

[4]. B. Bhushan, "Handbook of Nanotechnology," *Springer New York*, 2004.

[5]. M. Beckmann, H. A. Kolb and F Lang, " Atomic force microscopy of biological cell membranes: from cells to molecule. *EurMicrosc Anal*. ; 1:5–7 1995.

[6]. S Grover, D Lausch, M Werner, S Swatek, M Mergner, V Naumann and C Hagendorf,"Shunt analysis in Solar Cells Electro-Optical Classification and High Resolution Defect Diagnostics. *Energy Procedia* 27,7-12, 2012.

[7]. D. Westmoreland, M. Shaw, W Grimes, D. J. Metcalf, , J. J. Burden, K Gomez, , Knight and A E Cutler, "D F Super-resolution microscopy as a potential approach to diagnosis of platelet granule disorders. *Journal of Thrombosis and Homeostasis* 14, (4), 839-849, 2016.

[8]. V. R. Manfrinato, L. Zhang, D. Su, H. Duan, R. G. Hobbs, E. A. Stach, K. K. Berggren, " Resolution Limits of Electron-Beam Lithography toward the Atomic Scale," Nano Lett. 13, 1555-1558, 2013.

[9]. Y.J.Chen, J.H.Hsu, H.N.lin , *Nanotechnology*, 16, 1112, 2005.

[10]. D. Nyyssone and C. P.Kirk ," Optical microscope imaging of lines patterned in thick layers with variable edge geometry," *J. Opt. Soc. Am. A* .5(81) 1270-1280,1988.

[11]. M. H. Madsen and P.E. Hansen," Imaging scatterometry for flexible measurements of patterned areas," *Optics Express*, 24(2), 1109-1117,2016.

[12]. D. Liu, S. Wang, Pin Cao, Lu Li, Zhongtao Cheng, Xin Gao, and Yongying Yang," Dark-field microscopic image stitching method for surface defects evaluation of large fine optics, *"Optics Express*, 21(5),5974-5987, 2013.

[13]. K. Ullah, X Liu, N. Yadav, M. Habib, L, Song & B. Garcia-Camara," Light Scattering by Subwavelength Cu_2O Particle. *Nanotechnology*.(28),134002,2017.

[14]. K. Ullah X. Liu, X. Jichuan, J. Hao B. Xu, Z. Jun & W. Liu (2017), "A Polarization Parametric Method of Sensing the Scattering Signals From a Submicrometer Particle" *IEEE Photonics Technology Letters*, 29(1), 19-22, 2017.

[15]. B. Van der Linden, H. Terryn, and J. Vereecken , "Investigation of anodic aluminium oxide layers by electrochemical impedance spectroscopy," *J. Appl. Electrochem.*20 (5) 798–803, 1990.