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Surface topography analysis with application of roughness area dependence method

Adam Szyszka*, Mateusz Wośko, Tomasz Szymański, Regina Paszkiewicz

Faculty of Microsystem Electronics and Photonics, Wroclaw University of Technology, Janiszewskiego 11/17, 50-372 Wroclaw, Poland

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ABSTRACT

At the moment the root mean square roughness (R_q) is the most commonly used parameter for quantitative description of surface properties. However, this parameter has one main disadvantage: for its calculation only height variations of surface profile are used which are then represented by a single number.

To eliminate this restriction authors of the paper have developed a surface analysis method which is based on roughness calculation in the function of gradually increasing dimensions of a sampling area. By setting proper measurement parameters and further data processing, from R_q dependence on sampling area plot size there is a possibility to obtain more useful, additional information about specific surface properties than using the single roughness value.

Roughness area dependence plots, obtained from AFM images, were analyzed to study the influence of different growth parameters on surface properties of GaN layers and AlGaN/GaN heterostructures grown on sapphire and silicon substrates by Metal Organic Chemical Vapor Deposition (MOVPE) epitaxy. Although the method was used to characterize the semiconductor material in micrometer range, it can be applied also for any topography imaging technique in wide scale ranges.

1. Introduction

Surface roughness has a great impact on many physical phenomena including adhesion, lubrication, wetting, electrical and thermal conductivity as well as electromagnetic waves scattering [1]. Specifically, in the field of electronics and optoelectronics, the influence of surface and interface roughness on device and structure properties is observable as deviation of direct current, microwave and noise signal characteristics of MOSFETs [2,3], transmission losses in Si/SiO_2 waveguide system [4], electron scattering mechanism enhancement in quantum GaAs/AlAs wells and AlGaN/GaN heterostructures [5,6], reflectivity lowering of optical and acoustic Bragg reflectors [7,8], decrease of potential barrier height in Schottky diodes [9], and also in radiation reflection loss change in silicon solar cells [10]. Moreover, with further development of the semiconductor electronics, due to the decrease in characteristic dimensions of active elements, which leads to enlargement of surface to volume ratio, the importance of surface properties control and evaluation will be continuously increasing. Also research on fabrication and application of new materials in microelectronic devices requires intensive evaluation of surface quality which has to correspond with device mass production processing technology. At the moment, there are defined 59 statistical parameters for quantitative description of surface topography [11]. In addition to that, advanced analysis techniques, such as Fourier transform [12], wavelet and fractal theories [13,14] are used for surface properties description. However, in spite of such variety of available methods of surface evaluation, in most cases only the root mean square (RMS) roughness (R_q) parameter is used. Its dominant universality results from uncomplicated calculations and common understanding as a statistical factor which measures the discrepancy of surface profile from its mean value. On the other hand, this simplicity is the main disadvantage of the parameter because the information about surface topography is reduced to a single number. This could lead to uncertainty and distortion of conclusions, when samples with different surface topography are compared. It is schematically demonstrated on an example of various theoretical surface profiles presented in Fig. 1(a)–(e). Despite the profiles looking completely different and having distinctive features, all of them have the same calculated value of R_q parameter (0.707 in arbitrary units). In order to eliminate this restrictions authors of the paper have developed the roughness area dependence (RAD) method which bases on determination of R_q roughness dependence on the size of area used for the parameter calculation. By setting proper measurement parameters and data processing scheme, the plot of R_q in the function

* Corresponding author.
E-mail address: adam.szyszka@pwr.edu.pl (A. Szyszka).

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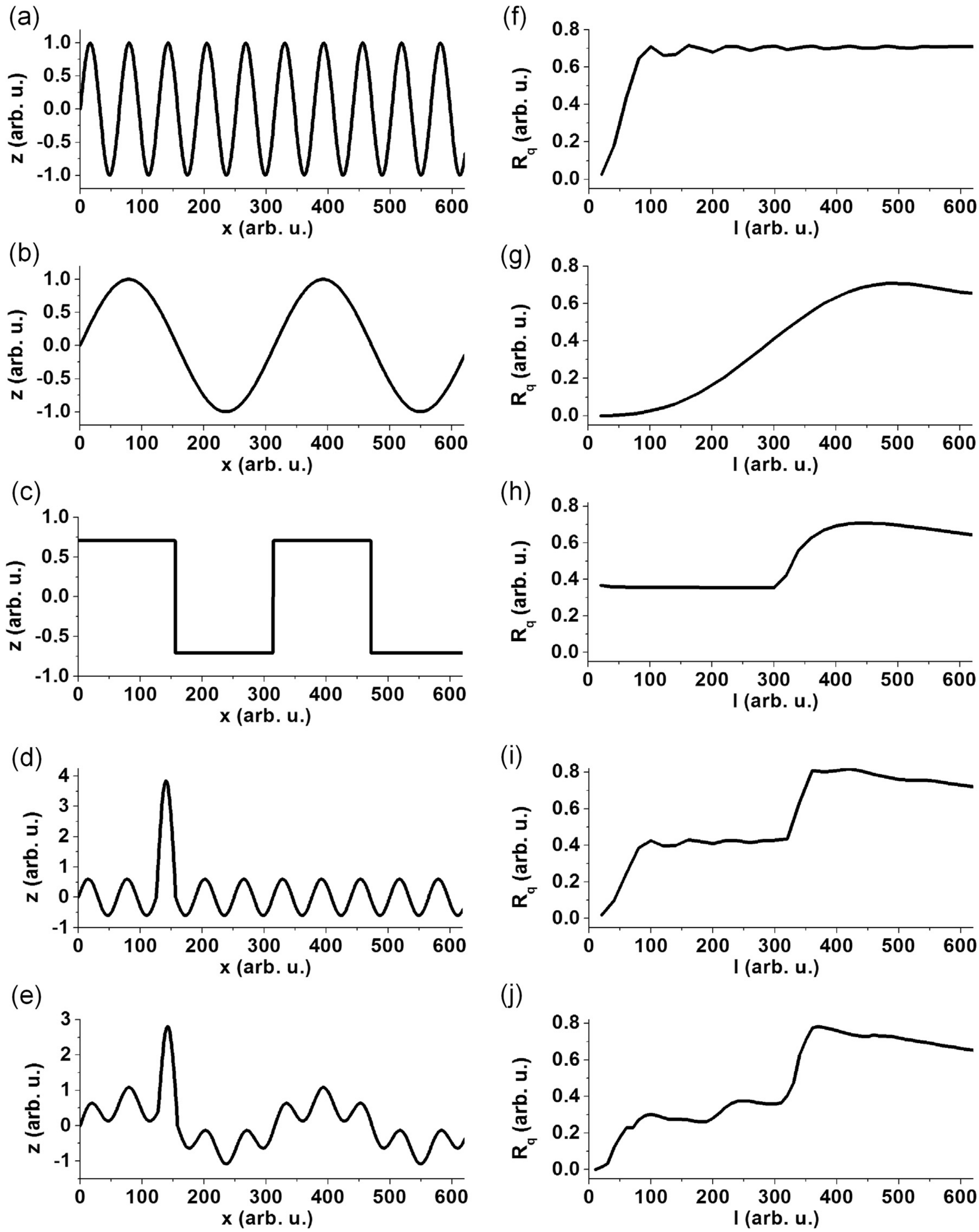

Fig. 1. (a–e) Various schematic profiles having the same value of root mean square roughness and (a–e) corresponding plots of R_q dependence on the sampling length.

of sampling area size allows one to obtain extended information on specific features of a sample topography. As an example of application of this method, an investigation of GaN layers and AlGaN/GaN heterostructures grown on sapphire and silicon substrates by Metal Organic Chemical Vapor Deposition epitaxy, imaged by atomic force microscopy (AFM) technique were performed.

2. Method description

In general, surface topography consists of repetitive or random three dimensional irregularities varying in vertical and horizontal dimensions. These irregularities could be described by waviness and roughness components which are defined in relation to the selected size of observation area [15], as schematically presented on the surface profile in Fig. 2. Surface features whose spatial dimensions are smaller than the observation length create surface roughness (Fig. 2b) and these whose size exceeds the observation length create waviness of the profile (2c) [16].

In roughness evaluation based on AFM topography measurement, selection of scanning area size determines which surface elements are classified as roughness or waviness components. It results, in many cases, in different values of root mean square