III-V Dry Etching by CCD-controlled in situ Interferometry

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Abstract

A novel method for in situ depth and reflectivity measurements during dry etching is presented in this paper. The method is based on laser interferometry with a CCD chip as the detecting element. This allows for a process alignment to typical critical layout structures using optical markers. The full in depth resolution of about 3 nm is available immediately after starting the etching process (no extrapolation of data). The lateral resolution of depth measurement is determined by the marker size (about 150x10 µm²). Using the same arrangement in the reflectivity mode (thin film interference), the lateral resolution is given by the pixel density of the CCD image and the optics itself. In the present case the lateral resolution is about 1µm². The method is now routinely applied for dry etch process control in MESFET, HBT and diode laser technology.

INTRODUCTION

The extensive demands on reliability and reproducibility of technological processes in microelectronics and microsystem technology require suitable methods of production process control. Therefore contactless measurement methods with nanometer scale resolution are required. In almost any cases only optical methods are able to fulfil these extremely high demands on resolution and accuracy [1-5].

A great variety of different methods are known for process control in plasma etching. They give information either on the plasma properties, the wafer surface or indicate the endpoint of the etching process. For the precise control of plasma etching the actual etching depth, the time dependence of the etch rate and the endpoint detection is decisive. The exact and reproducible knowledge of these parameters determines the stability of the process. Even in the case of material selective etching techniques it is important to know the actual etching depth in order to control lateral underetching in the presence of the etch-stop layer.

The interferometric method described in the following provides a direct insitu control of the etch depth and etch rate during dry etching. It can also be used to control the process by measurement of surface reflectivity and interference on thin layers. Modern process technologies demand for nanometer scale in depth and µm scale lateral resolution. The NanoMES insitu measurement system in combination with the pixel resolved insitu - interferometry developed by us meets these requirements. We have developed a method for end point detection with µm scale lateral resolution suitable for etching processes where layers to be structured are transparent for the analyzing HeNe-Laser.

PRINCIPLE OF MEASUREMENT

The basic principle of the method, the double beam interferometry is implemented in the „NanoMES" measurement device. As shown in Fig. 1 a beam splitter divides the light of a monochromatic coherent laser into two beams, an object beam and a reference beam. Since the two beams have different optical paths, interference patterns are obtained in the detection plane. A specially designed long focal optics depicts an image of the wafer surface of about 1 square millimetre on the CCD-matrix. If the object beam is projected on a flat wafer surface the phase shift in respect to the reference beam is the same for all pixels of the CCD-matrix. In the presence of any topology, on wafer altitude differences directly translate into different phase shifts of the respective pixels. Those pixels that are used for depth evaluation have to be defined before the measurement. For this purpose markers of about 150 microns length can be placed in the CCD-image and thus select well defined regions on the wafer surface. The reference markers are defined on top of the etch mask, the markers for etch depth evaluation are in regions that are to be etched during the process. In an etching process the altitude between the masked and the unmasked wafer surface is changing with etching time. A real time processing routine directly transforms this phase shift change into the altitude difference between the reference area and the measuring area. If the etching rate of the mask is negligible or small compared to the etching rate of the etched material, the phase shift difference directly represents the etch depth. The accuracy of determining the phase shift between the interfering waves relates to the minimum measurable altitude difference. Using appropriate techniques and algorithms, phase shift differences with an accuracy of 1/500 of the wave length used can be determined [6,7].

For a reproducible and reliable operation of the system it is crucial that the optical length of both interferometric arms is maintained absolutely constant during the integration time of the CCD camera which is about 40 ms. Disturbances can be caused by different influences such as temperature shift, mechanical shocks etc. To minimise these influences, stroboscopic measurements using a pulsed laser diodes are applied.

For interference on thin layers only the object beam is used. If the object beam is projected on a flat wafer each pixel of the CCD-matrix gives the intensity caused by interference on a transparent layer or the intensity of reflected laser light on a nontransparent surface. The software developed by us offers the possibility to set 4 markers on the surface region depicted on the monitor. In principle each pixel can be used as a measurement point. Thus the smallest markers are limited by the pixel size (1µm x 1µm on wafer surface). During etching the intensity time functions and the first derivation of intensities of selected pixels are displayed. This allows a µm-scale lateral resolution.

EXAMPLE

The capability of the measuring system „NanoMES“ was successfully implemented in the emitter dry etching step of a HBT fabrication process. For this purpose a SENTECH instruments plasma etcher (SI 591- parallel plate reactor with loadlock) was applied. A 30 mm central hole in the upper electrode of the plasma etcher allows for the optics of the „NanoMES“ system. The electrode perforation does not influence the etching homogeneity of the system. The dry etch process consist of 3 single etch steps:

- etching of WSiNx - measurement of reflectivity
- etching of InGaAs - measurement of depth (double beam interferometry)
- etching of GaAs with etch stop on AlGaAs- measurement of depth (double beam interferometry)

In the first step „NanoMES“ is used as device for measurement of surface reflectivity detecting the end point of etching. Because of changing reflectivity from higher values (WSiN surface) to lower values (i.e. GaAs surface) a well defined end point is visible.

In step 2 and 3 „NanoMES“ works as depth measurement device. During the process the actual surface reflectivity (1st step) and etching depth / etch rate (2nd and 3rd step) is depicted on a monitor. A typical process printout for a AlGaAs/GaAs HBT structure is explained in Figure 2. Figure 3 depicts a SEM micrograph of an emitter structure fabricated by using this technique. The technique allows to precisely control the emitter undercut all over the wafer. In principle variations of the undercut can be limited to those inhomogeneities being typical for the etching system and the etching parameters themselves.

The base sheet resistance of HBTs is a sensitive parameter to evaluate both, the homogeneity of processing and of epitaxy. The R_{sbi} map in Figure 4 a shows that this technique ensures good homogeneity all over a 4“-wafer.

CONCLUSIONS

For the first time a reproducible real time dynamic measurement of the etch depth during dry etching and a pixel resolved in situ measurement system for dry etching is offered by the interferometric system „NanoMES“. The minimum measurable altitude difference i. e. the deep resolution of the interferometer is about 3 nm. The only requirement on the probed material is a sufficient surface reflectivity. No other material data (e. g. refractive index) are needed for the evaluation.

„NanoMES“ provides a new level of precision and reproducibility in measurements of altitude differences that can be utilised in reproducible, precisely controlled etching processes. The control of the time behaviour of the etching provides additional important information on the stability and particularities of the process (e. g. induction periods, etching rate variations, material inhomogeneities etc.) „NanoMES“ is superior to commercial available interferometric systems, basing on thin film interferometry, because in contrast to all those systems the measurements principally start from zero. Multiple integers of l/2 need not to be known to calibrate the system. The relatively large working distance (in our case 200 mm) allows for a precise imaging of relevant structures on the wafer. This is an decisive advantage.

A deep resolution of the interferometer of about 3 nm and the very small lateral resolution of 1µm x 1µm for end point detection based on thin film interferometry makes the „NanoMES“ system to a very valuable tool for development and control of plasma- and ion beam etching processes. The system is routinely applied in HBT, MESFET and laser diode processes.

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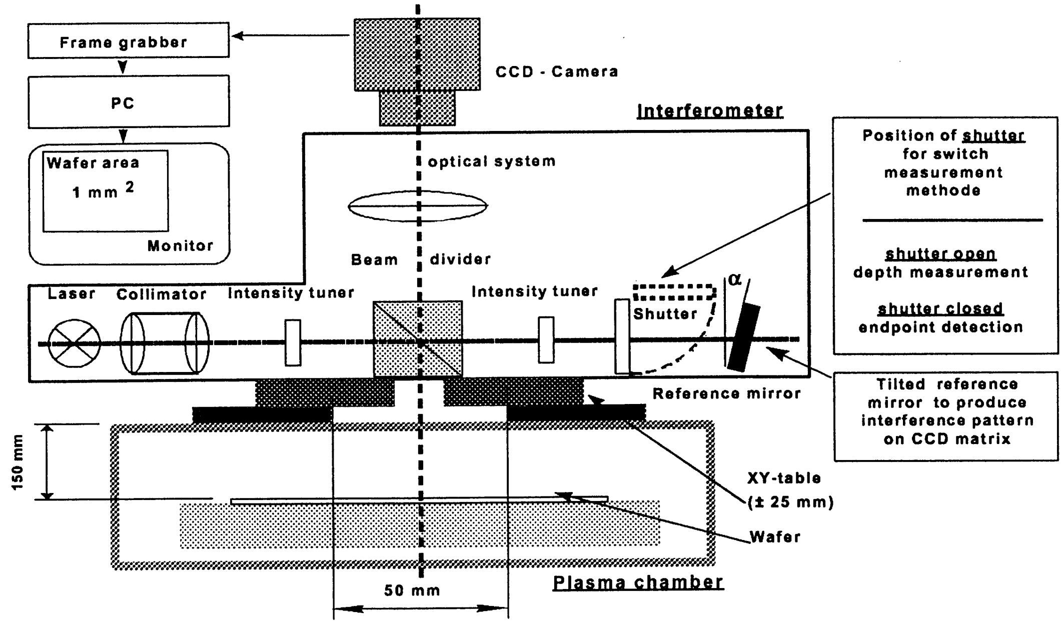

Figure 1: Setup of the interferometric measurement system (NanoMES)

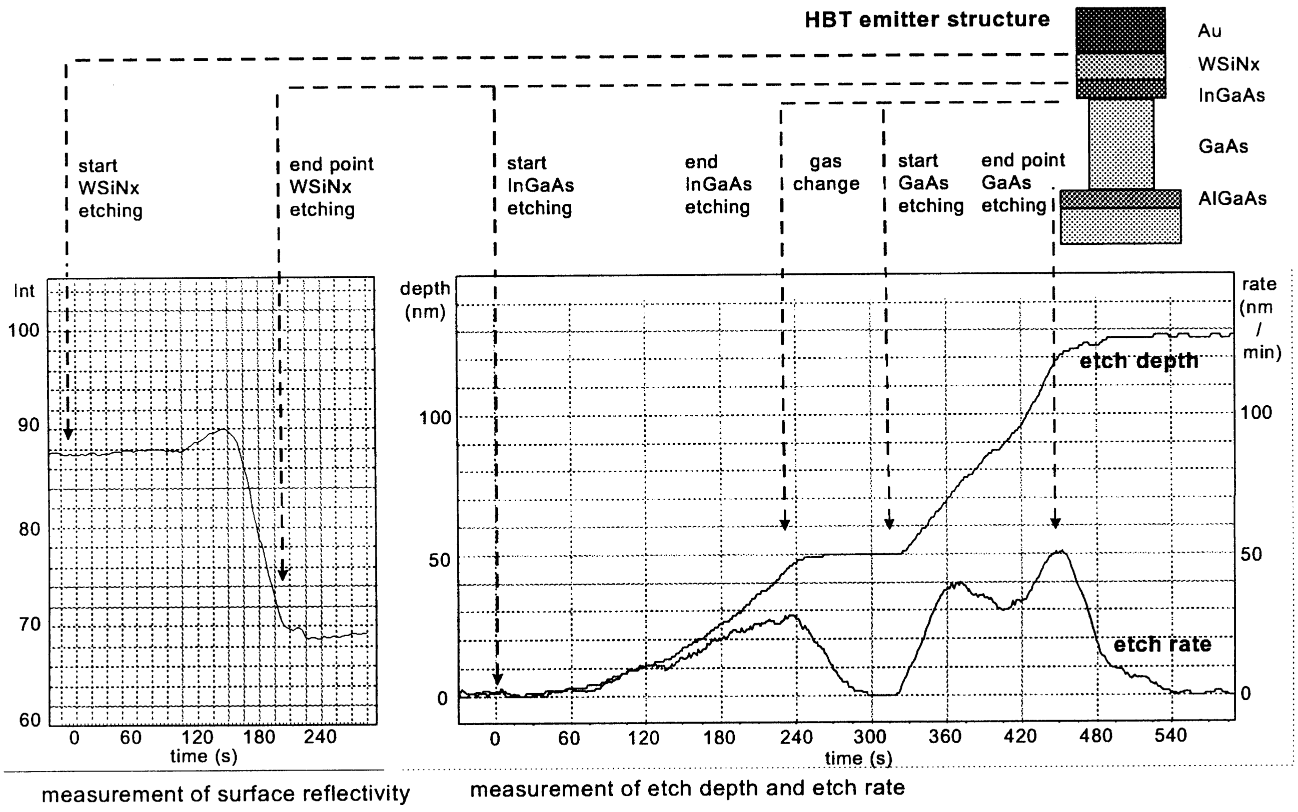

Figure 2 : Typical process printout during dry etching of an HBT emitter structure

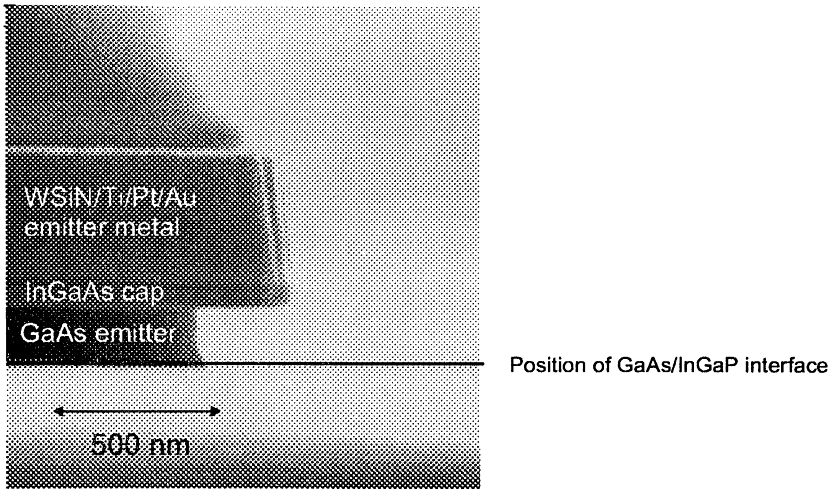

Figure 2: SEM micrograph of a InGaAs/GaAs/InGaP emitter structure etched by using insitu interferometry for process control

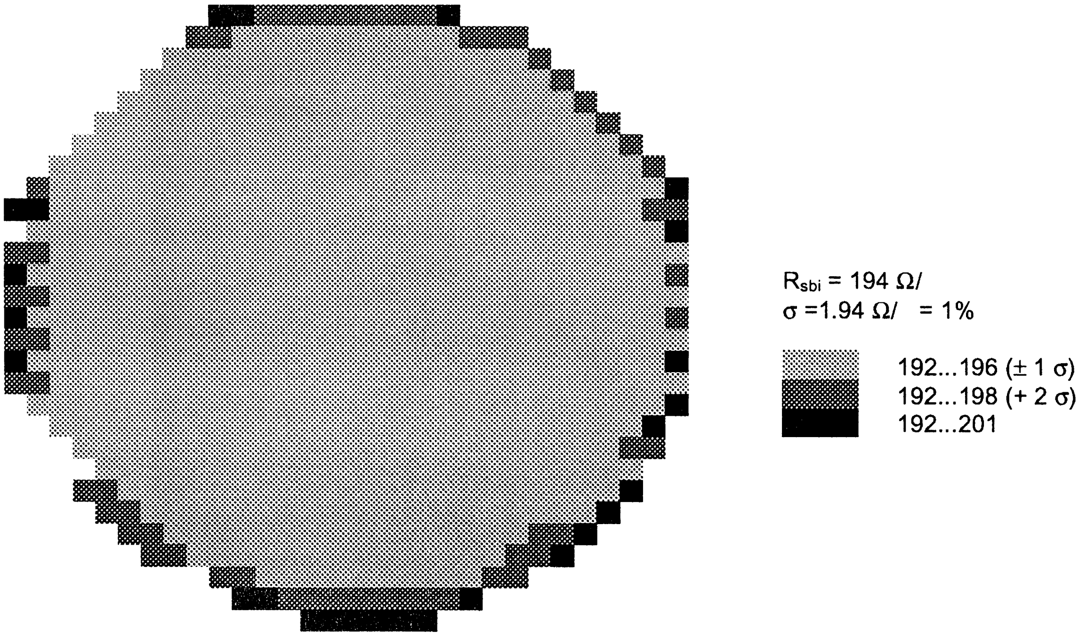

Figure 3: Homogeneity of the base sheet resistance R_{sbi} over a 4“-wafer