Extended Abstracts of the 1996 International Conference on Solid State Devices and Materials, Yokohama, 1996, pp. 607-609

AFM Direct Measurement of Sidewall Roughness in GaAs/AlGaAs Waveguides

K. Hosomi, M. Shirai, K. Hiruma, J. Shigeta and T. Katsuyama
Central Research Laboratory, Hitachi, Ltd., Kokubunji, Tokyo 185, Japan
Phone:0423-23-1111 ext. 31 05, Fax: 0423-27-7785

The direct measurement of sidewall roughness on a ridge-type GaAs waveguide was performed for the first time on AFM combined with a SEM. The ridge sidewall of a GaAs waveguide formed by wet-etching and the ridge sidewall after regrowth of a GaAs/AlGaAs layer were observed by introducing a technique for sample slanting. The observed power spectral density was used to estimate the scattering loss by the sidewall roughness. Furthermore, it was found that a periodical surface fluctuation along the wave guide appeared after regrowth of epitaxial layer.

1. Introduction

The study of fabrication of waveguide structures has recently become very important for making optical devices such as waveguide-type optical switches. [1] Such waveguides are usually fabricated by lithography, etching and regrowth. Therefore, the resultant geometrical imperfections such as surface fluctuations of the sidewall in a ridge-type waveguide cause a scattering loss. In particular, the effect of scattering loss arising from sidewall roughness becomes serious as width is reduced. Thus, to estimate transmission loss, it is necessary to evaluate sidewall roughness of the waveguide. Here, we report the first direct measurement of such sidewall roughness using an atomic force microscope (AFM) that is combined with a scanning electron microscope (SEM).

2. Experimental

Two types of samples were measured. The first had a ridge-type waveguide structure fabricated from the GaAs/AlGaAs epitaxial layer by EB lithography and subsequent wet chemical etching. The EB lithography was carried out with an ERIONIX ELS-3700 EB exposure system with acceleration voltage of 30kV. The waveguide structures were aligned in the [011] direction to obtain a mesa structure. The second sample was prepared by regrowth of the 2.45-μm GaAs/AlGaAs layer on the as-etched ridge structure fabricated by the above procedure. The regrowth was performed by metal organic vapor phase epitaxy (MOVPE). The growth temperature was 700℃ and the growth pressure was 150 torr. The topography of the waveguide sidewall was observed by a TopoMetrix TMX 2000 system. The AFM observer unit was mounted in the specimen chamber of the SEM, which enable SEM observation during AFM measurements. The mechanism for slanting the sample to make the sidewall close to horizontal was also introduced, as shown in Fig. 1. We adjusted the position of the tip on sidewall while observing SEM images. The scanning area was 2.3 μm square and vertical range was 0.87 μm.

3. Results and discussion

Figures 2(a) and 2(b) show AFM images of the as-etched first sample and regrown second sample, respectively. In these figure, the y axis show the [001] direction and the x axis shows the normal direction to the y axis along the side-wall surface. It is clearly seen that smooth surface became rough through regrowth. Note that the vertical scale is different between Fig. 2(a) and Fig. 2(b). The amplitude of the surface roughness of the regrown second sample is 6 times larger than that of the as-etched first sample.

Figures 3(a) and 3(b) show power spectral densities defined as the square magnitude of the Fourier transformation of the surface profiles shown in Fig. 2. For the as-etched first sample, as seen in Fig. 3(a), there is no significant difference in the power spectral density between the x and y directions. Furthermore the spectral density in both directions decrease with increase in spatial frequency. On the other hand, it can be seen from Fig, 3(b) that the spectral density function for the y direction has a noticeable peak around a spatial frequency of 2.2 μm^{-1}. This shows that roughness on the sidewall arising from MOVPE regrowth had a periodical structure with an amplitude as large as 150nm along y direction.

The scattering loss caused by the surface roughness can be evaluated quantitatively by using the obtained power spectral density.[2)] The scattering loss of the light wave was theoretically studied by Lacey and Payne in connection with the waveguides sidewall roughness[3)]. Here we focused our attention to the scattering loss for the wavelength of 1.5μm because of its importance in for conventional optical transmission applications. It is assumed that the core refractive index is that of GaAs (3.38 for 1.5μm) and core width is 1μm for simplicity. The cladding refractive index is fixed to be 1.0 (air). The determined scattering loss by the as-etched sidewall roughness is 0.03 dB/cm. Furthermore, a periodic surface fluctuation along the waveguide which appears after the regrowth gives the scattering loss 16 times larger than that of the corresponding as-etched surface.

4. Summary

Direct measurement of sidewall roughness on ridge-type GaAs waveguides was achieved with an AFM for the first time. SEM observation during the measurement and the use of a slanting mechanism enabled this measurement. The observed power spectral density can be used to estimate the scattering loss caused by the sidewall roughness. Thus this technique makes it possible to directly observe the sidewall roughness and to quantitatively estimate the sidewall scattering loss.

Acknowledgment

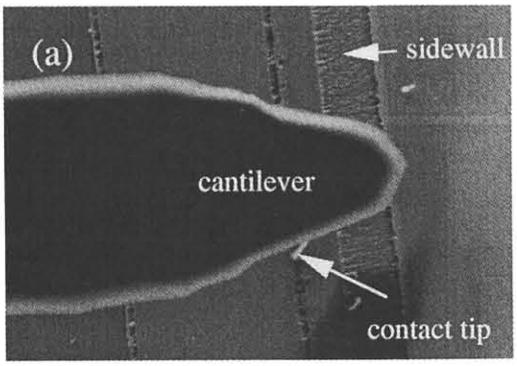
This work was performed under the management of FED as a part of MITI R&D Program (Quantum Functional devices Project) supported by NEDO.

References

1) J. T. Boyd, Integrated Optics: Devices and Applications (IEEE Press, New York, 1991).

2) F. Ladouceur, J. D. Love and T. J. Senden, Elect. Lett. **28** (1992) 1321.

3) J. P. R. Lacey and F. P. Payne, IEE Proc. J. **137** (1990) 282.



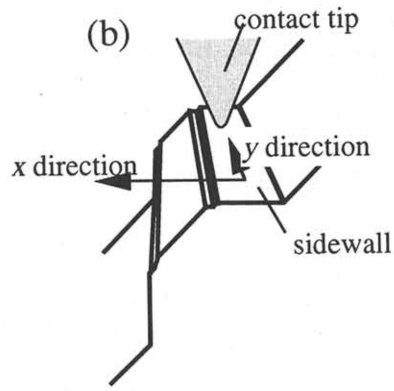
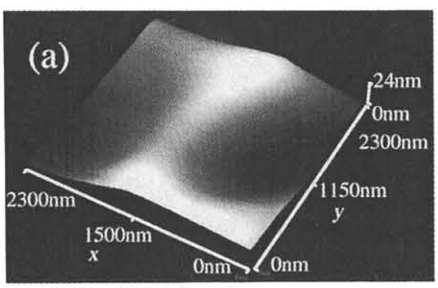


Fig. 1 (a) SEM image of the configuration of the AFM measurement. The sample shown was fabricated by regrowth of a 1- μm GaAs / 1.5 - μm AlGaAs layer on the etched ridge waveguide. (b) Schematic illustration.



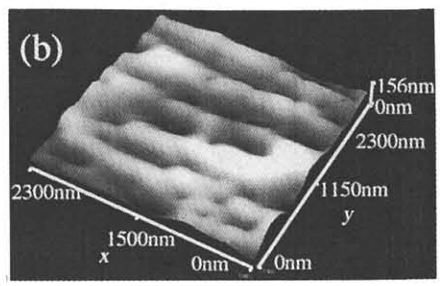
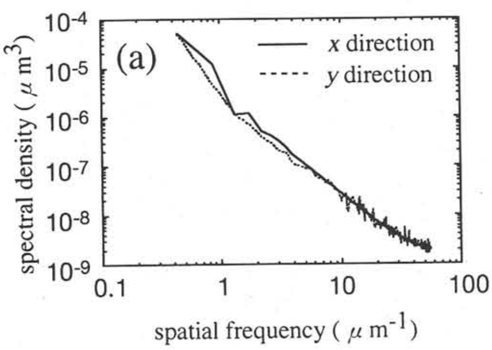


Fig. 2 Sidewall surface topography of waveguide measured with AFM. The coordinates are shown in Fig. 1.
(a) as-etched sample.
(b) regrown sample.



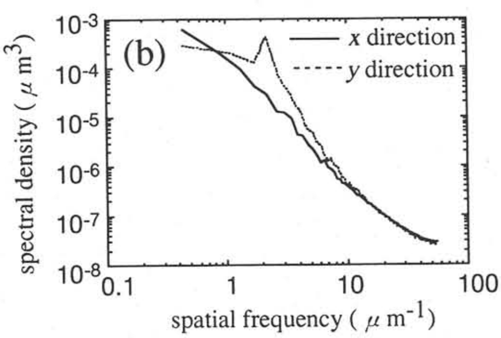


Fig. 3 Power spectral density defined as the square magnitude of the Fourier transformation of the surface profile.
(a) as-etched sample.
(b) regrown sample.