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A Broadband antireflection for GaSb by means of subwavelength grating (SWG) structures

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Abstract. Broadband antirefraction property is demonstrated by using subwavelength grating structures on GaSb wafers, which are the base material of GaSb PV cells. Surface nano-structure with 350nm periods is fabricated by means of electron beam lithography and fast atom beam (FAB) etching. Since FAB is electrically neutral atomic or molecular beam, it is possible to obtain fine patterns with nanometer order. The reflectivity of this sample is strongly suppressed from the visible to near IR region. The experimental data is compared with numerical simulations by using the rigorous coupled wave analysis. The thermal stability of SWG structures are also studied by measuring reflection spectra of heated samples.

INTRODUCTION

Antireflection coating on photovoltaic (PV) cells is very important for high efficiency thermophotovoltaic (TPV) systems. Multilayered coating of dielectric materials with different refractive indices is the most popular technique for PV cells. This technique has been well established and can be applied to wide surface area of PV cells. However, in some cases, the thermal stability of such multiplayer coating limits the performance of TPV, because the surface temperature of TPV cells is higher than that of the conventional PV cells.

A subwavelength grating (SWG), which is the surface-relief grating with the period smaller than the light wavelength, behaves as an antireflection surface [1,2]. The SWG with a deep tapered shape grating especially suppresses the reflection over a wide spectral bandwidth and a large field of view. The SWG is excellent in heat resistance because consisted of no materials except a substrate material. The schematic view of antireflection SWG is shown in Fig. 1. In order to achieve high performance SWG, the structural periodicity (Λ) must be smaller than the incident radiation wavelength (λ). A deep tapered

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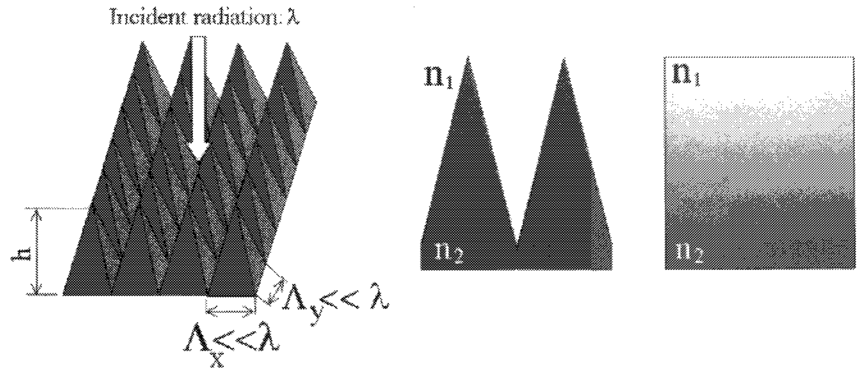

FIGURE 1. Schematic drawing of antireflection SWG (a), and the equivalent refractive index distribution along the light propagation direction (b).

shape is also important to obtain a broadband antireflection. The spectral properties of antireflection SWG can be explained by the graded refractive index model.

In this study, we have fabricated a two-dimensional antireflection SWG on a GaSb substrate. The SWG has consisted of 350 nm-period tapered grating. In the fabrication, electron beam (EB) lithography and fast atom beam (FAB) etching have been used. Since FAB is electrically neutral atomic or molecular beam, it is possible to obtain fine patterns with nanometer order. The reflectivity of the sample is strongly suppressed from the visible to near infrared region. The experimental data is compared with numerical simulations using the rigorous coupled analysis (RCWA). We have also demonstrated that the SWG works well for reducing the reflection even at the temperature of 240 °C.

FABRICATION PROCESS

We are studying the fabrication process of high performance selective emitter or absorber with surface microstructures[3-5]. In the case of selective emitters with surface microstructures, the structural periodicity is nearly equal the wavelength of thermal radiation, and the aspect ratio of unity is enough to obtain the sufficient performance in most cases. On the other hand, the most important properties of antireflection SWG are high aspect ratios and short periodicity of the grating. It is also necessary the two dimensional grating to obtain the characteristics independent on the polarization of radiation, The aspect ratio of 1 obtained by Han et al. using replication process had been the highest value in the two dimensional SWG [6]. Recently, two dimensional SWG with 150nm period and 350nm depth is fabricated on by Kanamori et al. on Si substrates [7] . Up to now, SWG has been fabricated on SiO_2 and Si in most cases.

The periodicity of SWG must be less than 450nm in order to match the spectral response of GaSb PV cells. In this study, the periodicity of SWG is fixed to 350nm.

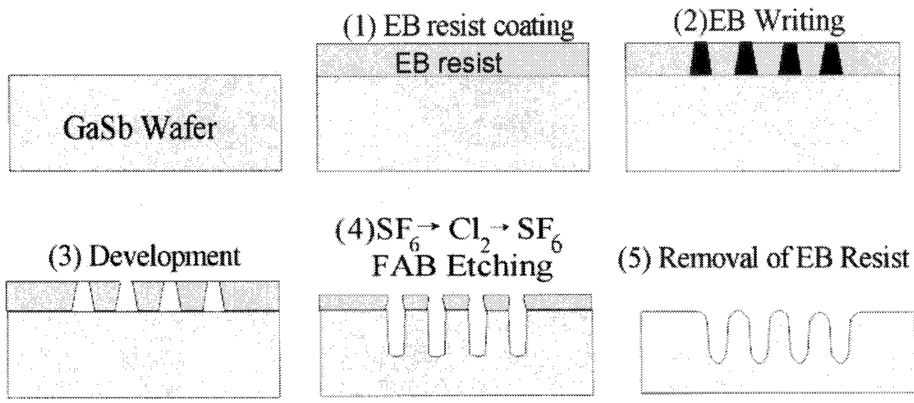

FIGURE 2. Fabrication process steps used in the fabrication of SWG.

This value was determined from both of fabrication reliability and performance of SWG.

The process steps used in the fabrication of the SWG are shown in Fig.2. A 500mm thick GaSb (100) wafers (p-type, carrier density;1~2 x 10^{17} cm^{-3}) is used as substrates. EB positive resist (Nippon Zeon Co., Ltd.; ZEP-520) is coated on the GaSb substrate by the spin coating technique. The thickness of EB resist is about 350nm. The SWG pattern is drawn on the resist by EB machine (ELIONIX Co., Ltd.; ELS3700). The EB resist is exposed by drawing the grating lines vertically and horizontally.

After the development, the resist grating is used as a mask for the FAB etching. In order to obtain the low spectral reflectivity, the gratings must have tapered shape as shown in Fig. 1. The tapered structure is fabricated by alternative FAB etching with two different kinds of gases. First, the GaSb substrate is etched by the FAB (EBARA Co., Ltd.; FAB-60ML) of SF_6 gas. In the second FAB etching, the Cl_2 gas is used. In the third FAB etching, the SF_6 gas is used again. In the SF_6 etching, the tapered grating shape is generated mainly by the physical spattering. On the other hand, for Cl_2 gas, the GaSb is etched vertically due to chemical reaction. By using the two etching gases alternately, the tapered grating with high aspect ratio can be fabricated. The EB resist is finally removed with tetrahydrofuran.

RESULTS AND DISCUSSION

Figure 3 shows the SEM images of fabricated SWG on a GaSb substrate. The grating with 350nm periodicity is fabricated in 1 x1 mm^2. From the analysis of SEM images, the depth of grating is estimated to be 1 μm. This result shows that the aspect ratio of fabricated SWG is about 2.86. This is the highest value of aspect ratio of two-dimensional SWG fabricated on III-V compound semiconductors. Furthermore, the fabricated SWG consists of a smooth tapered profile. Figure 4 shows the reflectivities of

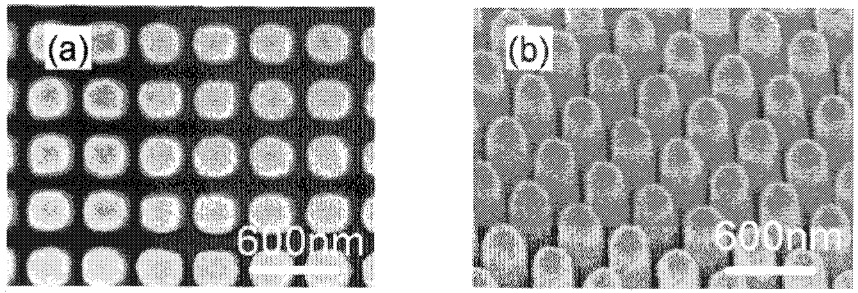

FIGURE 3. Top (a) and oblique view (b) of SEM images of fabricated SWG on GaSb

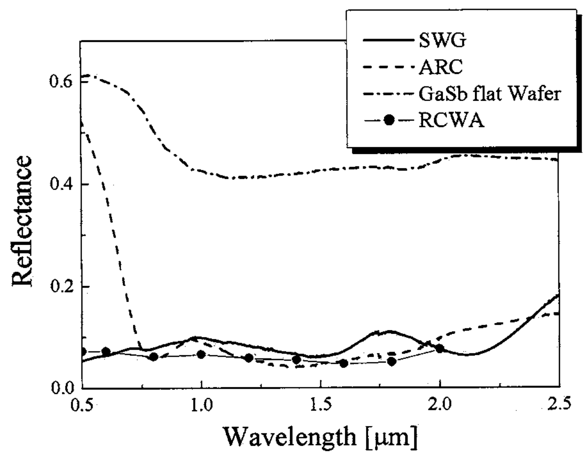

FIGURE 4. Reflectivities of the fabricated SWG and GaSb flat wafer as a function of wavelength. Reflection spectra of AR coated (ARC) GaSb using MgF_2/ZnS multilayers. The marked line represents the simulation result calculated by RCWA.

the fabricated SWG as a function of wavelength. Since the reflectivity of SWG shows angular dependence between incident and reflected light, we have used a diffused reflection geometry to measure the spectra. The reflected light within the angle of ±40° from the normal direction is collected in the measurement. The reflectivity of an antireflection coating (ARC) layer coated on the GaSb substrate is also measured. As shown in Fig.4, the SWG decreases the reflection drastically compared with that of the polished GaSb substrate. The reflectivity of the SWG is decreased as much as that of the ARC layer. At the wavelengths shorter than 0.75 μm, the reflectivity of the SWG is drastically decreased, while that of the ARC layer is increased with decreasing the wavelengths. The reflectivity of SWG is simulated by RCWA using literature data of optical constants of GaSb [8]. The

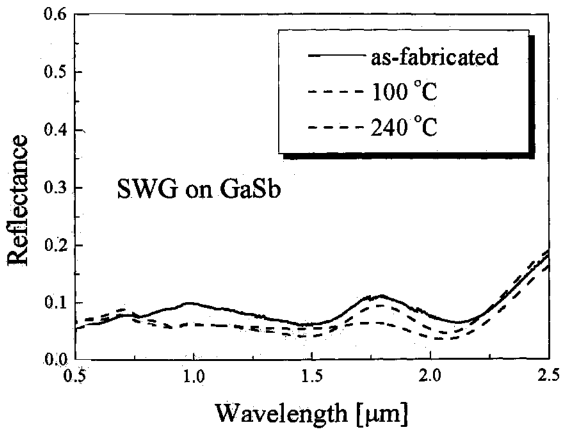

FIGURE 5. Reflectance spectra of SWS after heating tests.

reflection spectrum can be almost reproduced by the simulation over the measured spectral range. The simulation analysis reveals that the lower reflectivity can be achieved by the optimization of SWG structure.

The thermal stability of SWG was studied at 100°C for 36 hours. As shown in Fig.5, the antireflection property does not affected by this heat process. After the subsequent heating up to 240°C for 6 hours, there is no degradation of the property of reflectivity. This result indicates that the antireflection using SWG is effective for high temperature application of PV cells such as TPV.

CONCLUSIONS

We have successfully fabricated the SWG with the period of 350 nm on a GaSb substrate. The aspect ratio of 2.86 achieved in this study is the highest value of two-dimensional SWG fabricated on III-V compound semiconductors. For fabricating the tapered grating, which is essential to suppress the Fresnel reflection at the GaSb-air interface, we have introduced three-step FAB etching process using SF_6 and Cl_2 gases combined with EB patterning. The fabricated SWG has worked well for reducing the reflection even at the temperature of 240 °C. SWG shows good antireflection properties even for radiation with large incident angle. This property is very useful for TPV generators, because PV cells for TPV system are irradiated by thermal radiation with large incident angle range. It is confirmed that the GaSb PV cell with SWG will be powerful for improving the efficiency of TPV generation system.

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