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A GaAs/Air multilayer cavity for a planar-type non-linear optical device

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1. Introduction

Ultrafast all-optical switches operating in the 1.55 mm waveband are among the most important devices in high-bit-rate optical communication systems. Many types of switches exploiting the ultrafast nonlinear optical response of semiconductor materials have been reported. The enhancement of optical nonlinearity is required to achieve a high switching efficiency of all-optical devices. Recently, we have proposed a planar-type optical Kerr gate switch based on a half-wavelength (λ/2) cavity structure with GaAs/AlAs distributed Bragg reflector (DBR) multilayers. The internal light intensity of the cavity mode strongly increases in the λ/2 cavity layer. This enhanced light intensity enables us to use the nonlinear phase shift on the planar structure, which is particularly attractive for dense parallel processing and simultaneous multichannel demultiplexing. Moreover, we have revealed that the optical Kerr signal intensity can be further enhanced using excellent nonlinear materials such as self-assembled InAs quantum dots (QDs) only for the λ/2 cavity layer.

Optical cavities are usually characterized by their quality factor (Q) deduced from the spectral linewidth of the cavity mode ($Q = \lambda/\Delta\lambda$). The Q-factor, which is dependent on the number of periods of DBR layer (N), represents the enhancement factor of internal light intensity as well as the photon lifetime of the cavity mode. The enhanced optical Kerr effect in the N-period GaAs/AlAs multilayer cavity was studied by numerical simulation using the self-consist transfer matrix method. The simulation results revealed that the Kerr signal intensity increases in proportion to Q^4. [1] The strong optical Kerr signal enhancement with an increase in Q has been demonstrated in a GaAs/AlAs multilayer cavity with different N by time-resolved optical measurements in the 1.55 μm waveband. [2]

The Q of multilayer cavity depends on not only the number of DBR layers constructing the cavity but also the refractive index difference of two materials of the DBR layers. The refractive index difference between GaAs and Air (Δn = 2.4) is much larger than that between GaAs and AlAs (Δn = 0.5). Large Δn induces the GaAs/Air cavity, to have the Q factor of the same order of magnitude at much less number of DBR layers than that of GaAs/AlAs cavity. [3]

In this study, the optical Kerr signal and the internal electric fields in the GaAs/Air multilayer cavity were clarified by numerical simulation and a structure of the GaAs/Air multilayer cavity was fabricated.

2. GaAs/Air multilayer cavity structure

The optical Kerr signal and the internal electric fields in the GaAs/Air multilayer cavity were simulated by the self–consistent transfer matrix method. In our cavity structures, a λ/2 GaAs layer was inserted in the center of N periods of DBR multilayers. Figure 1 show the Q-dependent optical Kerr intensity for various number of DBR plotted on a log scale. Although the Q of the GaAs/Air cavity with 4-period DBR layers had the same order of magnitude of Q of the GaAs/AlAs cavity with 22-period DBR layers, the Kerr signals of the GaAs/Air cavity was two orders of magnitude larger than GaAs/AlAs cavity. Figure 2 shows the internal electric fields in the (a) GaAs/AlAs cavity and (b) GaAs/Air cavity. The maximum intensities of the internal electric fields in the GaAs/Air cavity were about 4 times larger than that of GaAs/AlAs cavity. The GaAs/Air cavity was quite effective for enhancing internal electric field because of the strong photon confinement. Higher intensity of the internal electric fields in the GaAs/Air cavity should cause stronger optical Kerr signals.

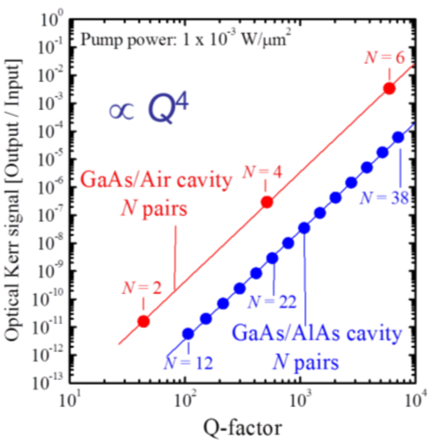

Fig. 1. Quality factor dependence of optical Kerr signal intensity of multilayer cavitities.

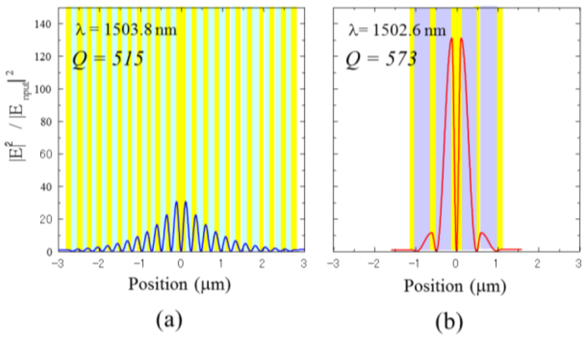

Fig. 2. Internal electric filed of
(a) GaAs/AlAs multilayer cavity (Δn = 0.5) and
(b) GaAs/Air multilayer cavity (Δn = 2.4).

2. Fabrication of the GaAs/Air multilayer cavity structure

We fabricated a GaAs/Air multilayer cavity structure and studied the optical characteristics. The structure consisted of a GaAs λ-cavity layer (444 nm) and 2-period GaAs/Air (333 nm/376 nm) DBR's on the both sides. Initially GaAs and sacrificial $Al_{0.67}Ga_{0.33}As$ multilayer structure was grown by molecular beam epitaxy on a (001) GaAs substrate. Two holes, which were 5 µm length , 3 µm width and 3.3 µm depth, were etched by the FIB (Forced Ion Beam) method or wet etching. The distance between the holes was 22 µm. Subsequently, sacrificial AlGaAs layers were removed by the wet hydrofluoric acid etching. Fig 3 shows a cross sectional SEM image of a GaAs/Air multilayer structure. It was observed that sacrificial AlGaAs layers were clearly etched from the side wall of the hole more than 13µm.

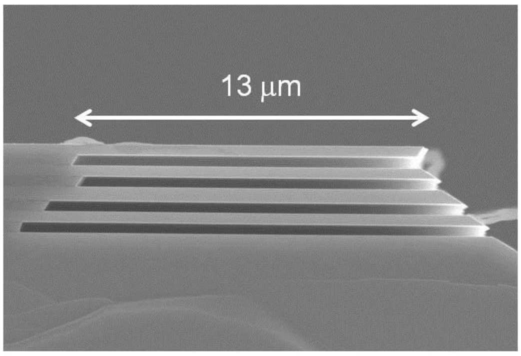

Fig. 3. The cross section SEM image of a GaAs/Air multilayer cavity.

Reflectivity spectra of the non-etched area and etched area were measured by a microscope with objective lens (10x). Measurement area of microscope was estimated to be about ϕ 10 µm. Figure 4 shows reflectivity spectrum of the (a) non-etched area and (b) etched area. The result was well reproduced by a simulation based on a transfer matrix method where oblique incidence to the objective lens (10x) with NA (0.3) was taken into consideration. In the measurement on the etched area, the observed area was set in the center of the two holes. The result showed a clear cavity mode at 1529 nm in the high reflection band.

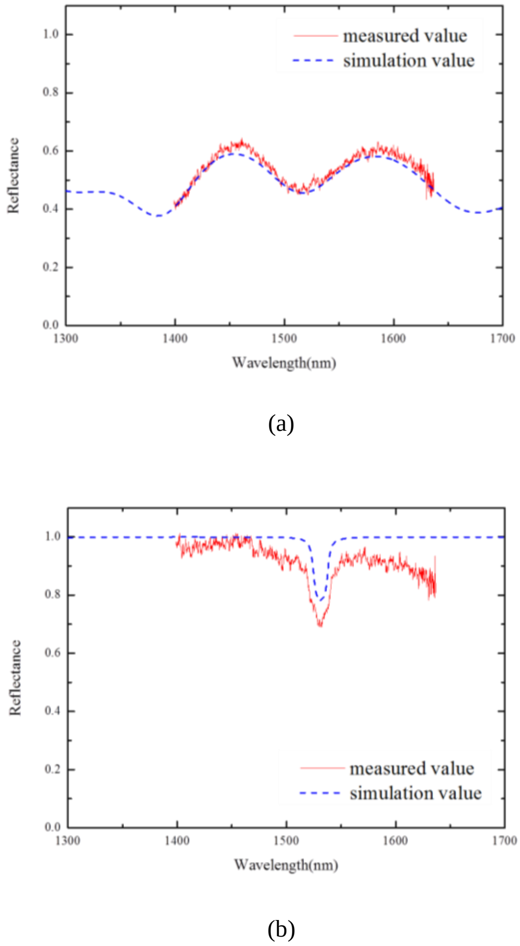

Fig. 4. The reflectivity spectrum of
(a) the non-etched area
(b) the eched area.

4. Conclusions

It is revealed the Kerr signals of the GaAs/Air cavity is expected two orders of magnitude larger than that of the GaAs/AlAs cavity for the similar *Q* values. In a cross sectional SEM image of a GaAs/Air multilayer structure, it was observed that sacrificial AlGaAs layers were clearly etched more than 13µm from the side wall of the hole. Reflectivity spectra of GaAs/Air multilayer cavity were measured by a microscope.The result showed a clear cavity mode at 1529 nm in the high reflection band.This indicates that we successfully fabricated the designed GaAs/Air multilayer cavity structure.

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