論文内容の要旨

論文題目

Integrated Bragg Grating and Carbon Nanotube Devices Using UV-Written Silica-Based Planar Waveguides

(紫外光描画石英系平面導波路によるブラッググレーティングと カーボンナノチューブ集積デバイス)

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Silica-based optical planar waveguide technology is promising to realize various functional devices. Recent requirements for optical devices are flexibility and cost effective fabrication. UV-written silica-based planar waveguide device is alternative option which may meet these requirements. However, silica-based waveguide devices are not suitable for realizing ultrafast tunable devices. Recently, carbon nanotubes (CNTs) for optical device applications are attracted much attention because of their ultrafast recovery time, third order high optical nonlinearity, etc. Structures of conventional devices based on CNTs have been all bulky, and they have a difficulty in integration. Another difficulty in CNT-based optical devices is handling of CNTs. In this thesis, we propose and realize a hybridization of silica-based optical waveguides and CNT devices to combine their advantages and compensate their disadvantages, and propose a novel handling method of CNTs based on optical tweezers.

Principle of fabrication technique of UV-written silica-based waveguides is photosensitivity. Photosensitivity, or UV-induced refractive index increase appears in Ge-doped silica-glass. By this refractive index increase, core-cladding refractive index contrast can be formed and desired waveguides patterns can be fabricated without any patterning masks. There have been realized various devices by this technique such as power splitters, directional couplers, etc. However, structures of UV-written waveguides have not been enough investigated compared with silica-based waveguides fabricated by Si-LSI fabrication technology. We measured cross sectional refractive index profiles of UV-written waveguides by refracted near field method, and found that refractive index distributions are Gaussian horizontally, and almost uniform vertically.

One of the advantages of UV-written waveguides is that the refractive index distributions can be easily formed by simply changing irradiation intensity of UV beam. Bragg gratings and sampled Bragg gratings are important elements which can be realized by refractive index perturbations in optical waveguides. We fabricated silica-based optical channel waveguides containing sampled Bragg grating using phase mask method. With 9mm-long sampled grating, we achieved 100GHz channel spacing and 98% reflectivity. Densification of channel spacing of sampled Bragg gratings for dense wavelength division multiplexed systems was conventionally achieved by elongating the total device size. Shortening device length is important especially for planar waveguide type devices because total device size directly determines the device cost. We introduced multiple phase shift technique to the sampled Bragg grating waveguides, and doubled the channel spacing to be 50GHz without elongating the total device length.

CNTs are attractive materials for photonic device applications because of their ultrafast recovery time, high nonlinearity, etc. Conventional CNT devices are all bulky and not integratable. We proposed planar waveguide-type CNTs devices. As a first step, we investigated a waveguide-type saturable absorber utilizing interaction between CNTs and evanescent wave. Planar waveguide-type saturable absorbers were realized by spraying purified CNTs onto over-cladding less silica-based optical waveguides fabricated by UV beam irradiation. We confirmed saturation of absorption by 3% when light from high power pulsed laser was incident. The device shows polarization dependence originated from the asymmetric structure, and polarization dependent loss over 15dB was observed. By using the saturable absorber, passively mode-locked fiber laser with pulse width as short as 187fs was realized. Another attractive characteristic of CNTs is their high optical nonlinearity which can shorten the sizes of optical nonlinear devices. All optical switching using CNTs' strong third order nonlinearity in nonlinear optical loop mirror (NOLM) configuration is investigated. Splitting ratio contrast of 20% using 1cm-long over-cladding-less CNTs-loaded planar waveguide was realized. This result indicates the possibility of integrated CNTs-based all optical switches realization.

Finally, we propose and demonstrate a novel fabrication technique of CNT devices. Handling the CNTs is one of the problems for device applications, and easy and cost effective handling technique of CNTs is required. Optical tweezer is the technique to manipulate micro-, nano-sized objects by focused light spot. By this technique, for the first time, CNTs were successfully deposited area selectively on the core region of end facets of optical fibers, and area selective deposition was confirmed by both Raman spectroscopy and field emission scanning electron microscopy (FE-SEM). We realized passively mode-locked fiber ring laser using the CNTs deposited fiber by optical tweezers. For precise control of CNT layer and estimation of CNT layer thickness and uniformity, we also developed an in-situ monitoring technique of CNT deposition process using optical reflectometry, and FE-SEM images supported the results. We also found that stable CNT sphere structure can be formed by optical tweezers, which may be useful for many applications.