Difference Frequency Generation in Microwave/Millimeter-Wave Rectangular Waveguide Embedded with Nonlinear Optical Crystal and Its Applications

Author(s)  
Ngo, Quang Hong

Citation

Issue Date

Text Version  
none

URL  
http://hdl.handle.net/11094/59080

DOI

rights

Osaka University Knowledge Archive : OUKA  
https://ir.library.osaka-u.ac.jp/repo/ouka/all/

Osaka University
Millimeter-wave/MHz waves are attractive for many fields such as broadband communications, imaging, sensor, radar, astronomy, and so on. Millimeter-wave/MHz waves are electromagnetic waves at boundary between the light wave region and radio wave region. Therefore, the techniques for the millimeter-wave/MHz waves generation are difficult and have been intensively researched. Nowadays, Difference Frequency Generation (DFG) based on the second order nonlinear optical effect is one of the potential techniques for the microwave/millimeter-wave/MHz-wave signal generation because it is possible to generate a signal at a desired frequency by simply adjusting the frequency difference between the input lightwaves. Furthermore, the generated power level increases as frequency increases. However, the current DFG devices are usually based on the bulk nonlinear optical crystal without the circuits for generated microwave/millimeter-wave/MHz-wave signals. There are some factors that make the conversion efficiency low such as difficulties in controlling the characteristics of the generated microwave/millimeter-wave signal and in the signal coupling. Research of DFG with circuits for the generated signal is required to solve these remain issues for further applications.

This thesis describes my study on microwave/millimeter-wave generation based on DFG in a rectangular waveguide embedded with the nonlinear optical crystal. This fusion of the nonlinear optical crystal and the microwave/millimeter-wave rectangular waveguide is a potential candidate for solving the remain issues of the current DFG devices. This thesis is constructed as following:

Firstly, the DFG in the rectangular waveguide embedded with the nonlinear crystal is presented. The characteristics of the DFG signal in a rectangular waveguide embedded with nonlinear crystal are analyzed by using the coupled-wave theory. These fundamentals are necessary for designing new microwave/millimeter-wave signal generation devices.

Secondly, a new microwave/millimeter-wave signal generation device using DFG in a LiTaO₃ rectangular waveguide is proposed. A periodically-poled structure is utilized to obtain quasi-phase-matching (QPM) between the lightwaves and the generated microwave/millimeter-wave signal. Characteristics of the device and its application to high frequency signal generation up to 100GHz are also analyzed. In the experiment, the prototype
of the QPM device is designed and fabricated at the frequency of 15 GHz. The microwave signal is successfully generated at the designed frequency from the fabricated device. The measured frequency response of the device was good agreement with the theoretically expected frequency responses. The experiment results confirm the theoretically expected characteristics of the proposed device.

Thirdly, I propose a new HFG-based microwave/millimeter-wave signal generation device with the phase matching QPM technique. The dispersion characteristic of the rectangular waveguide is utilized to obtain the PM condition between the input lightwaves and the generated microwave/millimeter-wave. An optical waveguide is utilized for diffraction-less light propagation through the device. The device has a very simple structure. The conversion efficiency is improved by 2 times compared with the QPM device. By reducing the cross-sectional size of the rectangular waveguide, the operational frequency can be shifted to a higher frequency range with keeping the PM condition. A PM device operated at 23 GHz is designed and successfully fabricated. The experiment for generation of the 23 GHz signal from the fabricated device is also demonstrated.

Fourthly, application of the proposed HFG-based devices to the optical signal correlation is presented. Two optical waveguides are utilized for launching two lightwaves to the HFG-based device, simultaneously. Two microwave/millimeter-wave signals are generated by HFG in two optical waveguides at the same time. Correlation of the two optical signals is performed in the microwave/millimeter-wave frequency range by HFG. Input lightwave coherences and spatial lightwave overlapping are not required.

Finally, the microwave/millimeter-wave circuits for improving the signal output from the HFG-based devices are proposed. The microwave/millimeter-wave signal transmission characteristics inside the device and the microwave/millimeter-wave signal emission from the end of the device to the air are analyzed by using the 3-D electromagnetic field analysis. Based on these microwave/millimeter-wave characteristics of the device, the new structures using a small hemispheric lens and horn-shaped waveguide for the coupling are proposed. The improvement of the coupling can be up to 40 dB with keeping the good resonator characteristics of the device.

論文審査の結果の要旨

マイクロ波からテラヘルツ波にいたる電磁波は、通信や測定、医療など様々な分野で利用されている。それに必須なコンポーネントである電磁波の発生は、通信の歴史そのものであり、発展可能な電磁波の周波数は年ごとに高く、正確な電磁波の周波数は年ごとに高まることで達成される。本論文では、マイクロ波からテラヘルツ波にいたるコヒーレントな電磁波の非線形光学効果による変調波発生について、方形状態変調法を用いた非線形誘電体構造を応用した構造を提案し、詳細な理論的検討を行い、デバイスの作製、動作の確認、さらにその応用について検討を行った結果をまとめるものである。

非線形光学効果を利用した変調波発生に関する報告はこれまでに多く行われているが、パルク結晶を用いたものが主であり、発生した電磁波の出力を制御することが困難であった。本論文では方形状態変調法に非線形誘電体構造を応用した構造を利用することで、応用に際しても有利である。変調波を発生するための2つの光を変調された光波と相対して、光検出器を用いることで、マイクロ波からテラヘルツ波までの電磁波を発生させることができる。この第2世代の光通信システムに利用されるUWMSの多段変調方式デジタルコリレート変調信号を直接発生可能で、ミクサや雑音回路が不要となる。

本論文では、まず方形状態変調法に非線形誘電体構造を応用した構造における変調波発生について結合モデル理論に基づき検討し、その基礎原理に関涉している。つまり、非線形媒質としてLiTaO₃を取り上げ、マイクロ波/ミリ波変調信号を提案している。ここでは、光波とマイクロ波/ミリ波間の準位相整合を得るため、周期非線形構造を利用している。信号波発生のための詳細な解析を行い、周波数が10 GHzで動作するディバイスを設計し、それに基づいたディバイスを作製し、動作確認を行った。得られた実験結果は予想された結果と良い一致を示している。さらに、方形状態変調法の分散特性を用いた構造を持つ変調波発生を示している。非線形媒質内をビームとして伝播させるのではなく、変調波路を制御させる良波と発生させる電磁波との結合を考え、テラヘルツ波まで発生可能であることを示している。周波数35 GHzで動作するディバイスを作製し、動作を確認している。また、相関変調型変調波発生の応用として、2つの変調波信号の相関をとるディバイスを提案している。相互コヒ