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Form 3

Abstract of Thesis

Name	（NGUYEN PHAM HAI HUY）
Title	Terahertz Device Characterization Based on Electro-optic Near-field Measurement (電気光学近接場計測によるテラヘルツデバイスの特性評価)

Terahertz (THz) waves, which are electromagnetic waves located at frequencies from 100 GHz to 10 THz, have been attracting lots of interest for practical applications to communication, sensing and measurement, owing to their unique and inherited properties from neighbor frequency regions, microwaves and light waves. In those applications, devices to manipulate THz waves such as antennas and lenses are important in addition to signal sources and detectors. The characterization of those devices are in urgent need of research and development. The near-field visualization of radiation and/or propagation of THz waves is greatly effective for the characterization.

Among various kinds of near-field measurement techniques, photonics-based technique to measure electric fields (E-fields) with use of an electro-optic (EO) crystal material is considered to be the most promising due to low invasiveness and wide bandwidth. The EO crystal is formed to the optical fiber-mounted probe, referred to as an EO probe, to enable an easy scanning over devices under test to visualize a dynamic three-dimensional E-field distribution. In general, however, one of the problems of the fiber-mounted EO probe is an instability of measurement due to a fluctuation of the sensitivity. Among several techniques to solve this problem, a nonpolarimetric detection scheme is adopted together with a self-heterodyne technique throughout this study because of its simplicity and simultaneous acquisition of both amplitude and phase information of the E-field. Other practical issue in the EO probe is a poor sensitivity, which limits the applicability of the EO measurement below the frequency of 100 GHz.

The objective of this study is to expand use of the EO probe in the characterization of THz-wave manipulating devices at frequencies from 100 GHz to 500 GHz, and to show “value” of the EO near-field measurement by demonstrating essential results of THz device characterization. Novel approaches are proposed to enhance the sensitivity and to reduce the invasiveness in the nonpolarimetric self-heterodyne EO detection system.

First of all, a DAST organic material, which exhibits a large EO coefficient, was employed to improve the sensitivity by 6 dB to 0.28 V/m at both 100-GHz and 300-GHz bands. A new scheme employing differential detection to reduce common laser noise by 4 dB was also introduced. A Styrofoam holder, which has the refractive index close to air, was introduced to reduce the invasiveness by 8 dB. The origin of the issue of unwanted phase front appearing in the amplitude images was investigated, and effective solutions based on signal processing and hardware improvement were proposed.

Then, the real impact of EO probe was demonstrated by characterizing several THz devices, which include antenna, metal hole array (MHA), spherical-wave generation device, and near-field localizing device, referred to as “terajet”. The results of characterizing antennas confirmed the effectiveness of near-to-far-field transformation technique employing the EO probe. The first experimental verification of beam collimating phenomenon in the MHA and the explanation of physical mechanism were described. The characterization of spherical-wave generation device was performed up to 500 GHz. The obtained results also confirmed that the EO probe can diagnose malfunction at high frequency of this device. The terajet-generation was successfully observed and characterized under different illumination conditions.

Finally, two practical applications of the terajet were proposed and experimentally demonstrated. One is to enhance the sensitivity of the EO probe, and the other is to enhance the spatial resolution of THz imaging systems.

様式７

論文審査の結果の要旨及び担当者

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論文審査の結果の要旨

マイクロ波と光波の中間に位置する、周波数100GHz～10THzの電磁波は、テラヘルツ波と呼ばれ、２１世紀に残された最後の周波数帯のフロンティアとして、通信、センシング、計測等の実応用に向けた研究開発が活発になっている。このような応用においては、テラヘルツ波の発生素子や検出素子に加え、アンテナやレンズのようなテラヘルツ波を操作するための受動素子が重要であり、これら受動素子の特性を評価するための技術が不可欠である。特に、アンテナやレンズの近接場電界の放射や伝搬の様子を可視化することは、その特性評価に極めて有効である。

本論文は、電気光学（Electro-optic: EO）結晶材料を用いて光学的に近接場電界を計測する技術、いわゆる電界可視化技術において、測定感度と擾乱の問題を解決することに取り組み、実際に100GHz～500GHzの周波数帯で動作する素子の評価に適用し、その有用性を実証したものである。具体的には、まず、自己ヘテロダイン法を用いた非偏光検出に基づく、光ファイバー型EO計測システムにおいて、DAST結晶や差動検出法の導入による感度増強法と擾乱の低減化手法を提案している。次に、そのシステムを用いて、アンテナ素子、メタルホールアレー素子、テラジェット素子等から放射される電界を可視化し詳細な特性評価を行って、各々の素子の物理的な振る舞いを解析している。さらに、計測対象であったテラジェット素子を使って、EO計測システムのさらなる感度増加を図ること、またイメージング技術に適用して空間分解能の向上を図ることを提案、実証している。

以上、EO計測による電界可視化技術を使い、テラヘルツ波素子を高感度かつ低擾乱に評価するための手法は独自性と実用性が有り、またそれを用いての様々なテラヘルツ素子の評価結果は、工学的に極めて大きなインパクトを与えるものであることから、本論文は、博士（工学）の学位論文として価値のあるものと認める。