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研究課題名（和文）Real-time THz wave near-field camera with metamaterial devices

研究課題名（英文）Real-time THz wave near-field camera with metamaterial devices

研究代表者

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研究成果の概要（和文）：フィルムデバイスによる2層スプリットリング共振器（SRR）を備えたメタマテリアルがフォトリソグラフィー技術で実証されました。40、26と15ミクロンの膜厚を持つ2層SRRデバイス、30mm x 30mmの均一なフィルムが開発されました。開発されたデバイスは、THz-TDSによって測定され、スペクトル性能を確認しました。 シミュレーション結果とよく一致しています。デバイスプロセスと設計の最適化中に、2層の金属パターンを持つフィルムメタマテリアルに基づく高透過THz波1/4波長板も実証されました。二重層金属パターンと共振モード近接場結合はテラヘルツ波デバイスの性能に重要な役割を果たします。

研究成果の学術的意義や社会的意義
Film metamaterial has flexible and thin thickness properties, which can be used in several applications including near-field imaging, sensing, etc. The development of the film metamaterial and the analysis of near-field coupling for the metamaterial design can serve as preliminary work for future.

研究成果の概要（英文）：Metamaterial with double-layer split ring resonators (SRRs) by a film device was demonstrated with photolithography technique. Devices with film thickness of 40, 26 and 15 micron were developed, both with double-layer SRRs. The film release procedure was checked with several temperature conditions and optimized to a range around to a range about 45 degC. Finally, uniform films with size of 30 mm by 30 mm were obtained. The developed devices were measured by THz TDS (THz time domain spectroscopy) for checking the spectra performance, which well matched with the simulation results. During the optimization on the device process and design, a high transmission THz wave quarter wave plate based on film metamaterial with double layer metallic patterns was also demonstrated. We analyze the effects introduced by the near-field coupling between the doublelayer metallic patterns and the resonance modes. The near-field coupling plays an important role in the THz-wave device performance.

研究分野：metamaterial

キーワード：metamaterial　double-layer pattern　resonance mode　near-field coupling

1. Scientific background of the research

THz wave is an electromagnetic wave with the frequency range located between microwave and infrared. Since the unique fingerprint properties on many materials, THz wave has attracted lots of research interests, such as using THz-TDS (THz- time domain spectroscopy) to analyze the molecular composition. On the other hand, THz wave imaging as an update technique to directly observe the sample characteristic substantially benefits the applications in security checking, electronic device diagnoses, nondestructive quality monitoring (tablet film, plastic weld joints), bio and medical analysis, etc. Among the THz wave imaging techniques, THz-wave near-field imaging with the resolution in submicron or nanometer level is desired to observe the matter-THz wave interaction and the chemical analysis for bio applications. While in the traditional THz-wave near-field imaging single probe technique [1] is normally used which takes long time for a whole set scanning and limits the operation speed. On the other hand, the real-time THz wave image demonstrated in reference [2] shows promise for the technical transformation to the industry. However, the image resolution is poor and the up-conversion efficiency of the DAST (4-N,N-Dimethylamino-4'-N'-methylstilbazolium tosylate) crystal is low for the THz wave detection. A system with real-time feature and also holds fine resolution will benefit the research community.

Metamaterial as an artificial material with engineered metallic patterns (e.g. split ring resonator SRR) on a specific substrate (semiconductor or insulator) brings potential opportunity to develop novel electromagnetic devices by its ability to tailor the wave propagation, especially for the limited effective components in the THz frequency range. Recently, researchers begin to use metamaterial for the image system, such as the metamaterial lens [3], THz wave spatial light modulator [4]. Flexible THz metamaterial devices have also been reported [5], which are in sub-wavelength thickness and has the potential to integrate with other THz devices for compact THz photonics.

2. Purpose of the Research

A flexible metamaterial device with sub-wavelength thickness was proposed for real-time THz-wave near-field imaging. The metamaterial composed of double-layer SRR array works as a probe array to collect the object near-field information. Because of the sub-wavelength property of the metamaterial, the double-layer SRR array can transfer the probed near-field information to the nonlinear crystal (DAST), where through the optics up-conversion with the nonlinear crystal, one can obtain the THz wave image of the original object. A polymer Benzocyclobutene (BCB) was used for the substrate of the metamaterial device, which enables the sub-wavelength thickness of the metamaterial and flexibility of the developed device.

3. Research methods

The double-layer SRR metamaterial was designed by considering the items related with the near-field coupling within the metamaterial unit structure of SRRs, the phase matching condition with DAST crystal, and the spectra transmission, etc. Simulation (commercial package COMSOL & HFSS) was conducted for the double-layer SRR design, with investigation on the spectra performance, the surface current and electric field distributions. Next, the device process was conducted in a class-1000 clean room with photolithography and MEMS (micro electro mechanical system) micromachining technique.

4. Results

(1) Metamaterial double-layer SRRs device design

The metamaterial double-layer SRRs design strategy is shown in the following Fig. 1. There are 5 items needing to be considered for both the THz wave near-field reservation and the nonlinear efficiency improvement at the DAST surface by the electric field enhancement. BCB is suggested for the substrate due to low electromagnetic loss and the process compatibility.

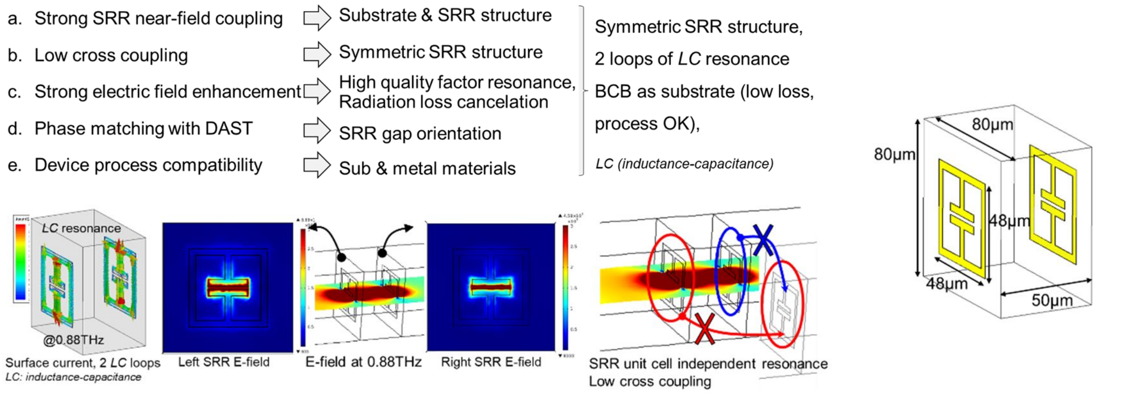

Fig. 1. Metamaterial design. Left-part: left-side, surface current distribution; middle, electric field (E-field) distribution of SRRs plane; right-side, consideration on the potential cross couplings from neighbors→symmetric structure has low cross coupling. Right-part: schematic of the double-layer SRRs metamaterial unit structure.

(2) Device process

Photolithography and MEMS surface micromachining techniques were used for the device process. The process begins on a handle wafer with depositing the sacrificial layer. After that, a thin polymer film is spinning-coated on the wafer with the subsequent curing process in a vacuum oven. Then the 1st metallic pattern is patterned by photolithography and wet etching process. The spacer polymer film with designed thickness from the electromagnetic performance is spinning coated on the SRR structures with the additional curing process, followed by the 2nd layer SRR patterning. Slightly misalignment (~1μm) between the doble-layer SRRs is tolerant with the design from the electromagnetic view, which enables the device process in reality. Eventually, the film device with double-layer SRRs is released from the handle wafer, as shown in Fig. 2. The thickness of the developed device is estimated to be 26 μm, which is deep sub-wavelength, satisfying the near-field coupling requirement of the probe.

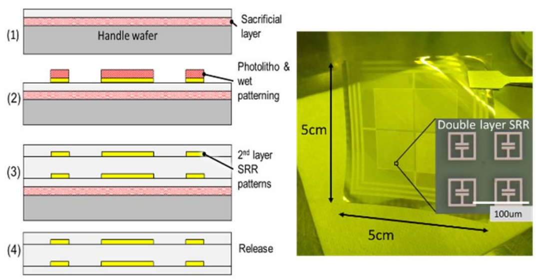

Fig. 2. Developed film metamaterial with double-layer SRRs.

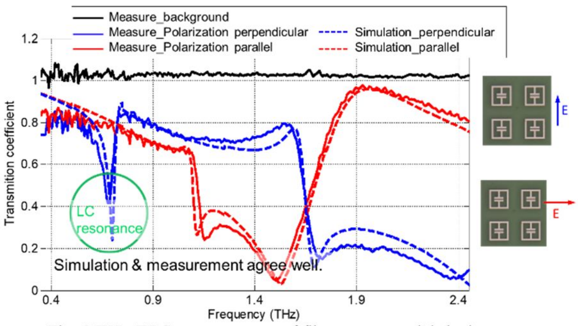

Fig. 3 THz-TDS measurement of film metamaterial device.

(3) Device characterization

The developed film metamaterial device was characterized by THz-TDS for its spectra performance to check its design. The results are presented in Fig. 3. During the measurement, THz wave was normal incident to the film device. The polarizations were either parallel to the SRR gap or perpendicular to the SRR gap. Figure 3 indicates that simulation and the measurement have excellent agreement, which confirms the metamaterial design with the near-field coupling in between the double-layer SRRs, which works as the near-field probe of the object in THz wave imaging.

(4) THz-wave quarter wave plate (QWP) development

During the design for the double-layer SRRs metamaterial, a THz-wave QWP was also studied. The design of the THz-wave QWP also employ the double-layer SRRs metamaterial, but instead of the square frame for the SRR, the QWP design used a rectangular frame for the SRR, as shown in Fig. 4.

The metamaterial unit structure employs a 2-fold symmetric structure SRR, which introduces the artificial birefringence that is necessary to build a quarter wave plate. In order to achieve the high transmission, double-layer metallic patterns were used. For the working frequency band of the THz-wave QWP shown in the green strip in Fig. 4, it was chosen in the region of off from inductor-capacitor (LC) resonance at TE mode to have the high transmission, and in the region of anti-parallel dipole resonance at TM mode to obtain the high transmission. Apartment from high transmission for both modes, a phase difference of 90 degrees is obtained, indicating the good performance for a transmission type THz-wave QWP.

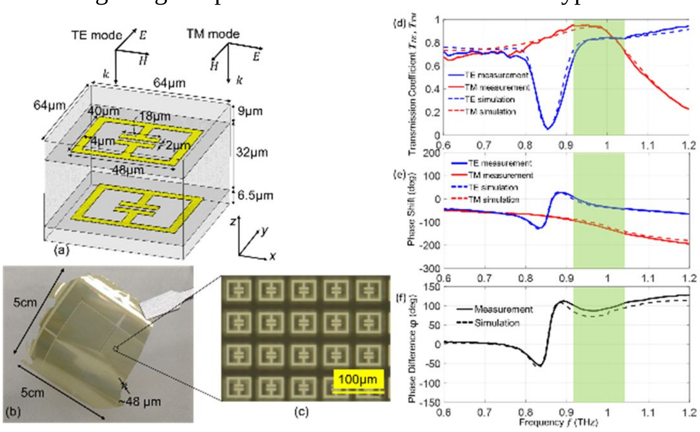

Fig. 4. High transmission THz-wave quarter wave plate.

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５．主な発表論文等

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２．論文標題 Off-resonance and in-resonance metamaterial design for a high-transmission terahertz-wave quarter-wave plate	５．発行年 2018年
３．雑誌名 Optics Letters	６．最初と最後の頁 2977-2980
掲載論文のDOI（デジタルオブジェクト識別子） https://doi.org/10.1364/OL.43.002977	査読の有無 有
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１．著者名 Han Zhengli、Ohno Seigo、Tokizane Yu、Nawata Kouji、Notake Takashi、Takida Yuma、Minamide Hiroaki	４．巻 25
２．論文標題 Thin terahertz-wave phase shifter by flexible film metamaterial with high transmission	５．発行年 2017年
３．雑誌名 Optics Express	６．最初と最後の頁 31186～31186
掲載論文のDOI（デジタルオブジェクト識別子） https://doi.org/10.1364/OE.25.031186	査読の有無 有
オープンアクセス オープンアクセスとしている（また、その予定である）	国際共著 -

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〔図書〕　計0件

〔産業財産権〕

〔その他〕

The film metamaterial process technique developed in this work was transferred to a company (フラクシ株式会社 (英文表記　PHLUXi, Inc.) http://phluxi.com/jp/).

６．研究組織

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