論文 / 著書情報
Article / Book Information

題目(和文)	
Title(English)	A study on photo-thermoelectric sensor array sheets and three-dimensional non-destructive inspection applications
著者(和文)	李恒
Author(English)	Kou Li
出典(和文)	学位:博士(工学), 学位授与機関:東京工業大学, 報告番号:甲第12379号, 授与年月日:2023年3月26日, 学位の種別:課程博士, 審査員:小寺 哲夫,波多野 睦子,若林 整,飯野 裕明,岩﨑 孝之,河野 行雄,長汐 晃輔
Citation(English)	Degree:Doctor (Engineering), Conferring organization: Tokyo Institute of Technology, Report number:甲第12379号, Conferred date:2023/3/26, Degree Type:Course doctor, Examiner:,,,,,,
学位種別(和文)	博士論文
Category(English)	Doctoral Thesis
種別(和文)	論文要旨
Type(English)	Summary

（博士課程）
Doctoral Program

論 文 要 旨

THESIS SUMMARY

系・コース： Department of, Graduate major in	電気電子 電気電子	系 コース	
学生氏名： Student's Name	李 恒		

申請学位（専攻分野）： Academic Degree Requested	博士 Doctor of （ 工学 ）
指導教員（主）： Academic Supervisor(main)	小寺 哲夫
指導教員（副）： Academic Supervisor(sub)	河野 行雄

要旨（英文 800 語程度）
Thesis Summary（approx.800 English Words ）

This study develops multi-functional photo-thermoelectric (PTE) sensing/imaging systems by designing ultrabroadband and stretchable detector array sheets with single-walled carbon nanotube (SWCNT) films. PTE conversion with the CNT film channel and mechanical sheet design play an essential role in demonstrating ultrabroadband photo-detection and collectively satisfying physical durability and optical stability.

Photo-monitoring measurements allow non-contact acquisition of optical information for monitoring targets in a large area. The optical properties of various objects are typically variable in monitoring wavelengths or bands. This inherent nature of photo-irradiation enables hyper-spectral material identification of composite objects by aggregating optical properties at multiple wavelengths or non-contact structural reconstructions of layered targets by analyzing the degree of transmission, reflection, and absorption. Therefore, photo-monitoring measurements play a leading role in non-destructive inspection techniques. In particular, photo-imaging is effective in aggregating multiple-points optical information in large areas of target objects in a non-destructive and non-contact monitoring manner. This feature potentially contributes to realizing real-time evaluations of whole targets themselves.

To handle diverse materials or objects consisting of these in non-destructive inspections, the effective use of longer-wavelength light over typical X-ray, ultraviolet, and visible light (Vis) bands is a potential approach. Here, longer-wavelength light includes millimeter- or terahertz-waves (MMW, THz) and infrared light (IR). Irradiation in these bands exhibits transparency to even non-metallic opaque objects compared to Vis, with much lower invasiveness than that with X-rays. Fingerprint spectra or intrinsic absorption characteristics often exist in these bands (e.g., polymers and gases), and such features enrich non-destructive inspection techniques. These situations emphasize the broadband operation of photo-detectors is indispensable since industrial components and infrastructure facilities mostly comprise composite and layered materials.

To further relaxes environmental limitations in non-destructive inspections, developing shape deformable device configurations allows omni-directional and blind-spot-free 3D monitoring by surrounding targets with photo-detectors without bulky rotation stages. Such device flexibility and stretchability contribute to monitoring even transformable objects by firmly wrapping them and stably following dynamic deformations modulated by the inherent softness of the targets. Curved structures often serve as containers or outer housing of industrial components and infrastructure facilities, and bring blind spots for rigid photo-detectors. Therefore, the development of broadband and stretchable photo-detectors is in demand. However, investigations of such photo-detector development are still incomplete.

To this end, this study focuses on the advantageous PTE effect as the photo-detection mechanism compared

with other approaches. The PTE effect allows ultrabroadband photo-detection over the electronic-type method with uncooled operations over the photon-type mechanism. The uncooled device operation facilitates mobile systemization of non-destructive inspection techniques, being free from bulky cooling equipment. The PTE effect also realizes photo-detection with lower noise by functioning without applying a voltage bias compared with the bolometric approach. This study then employs the SWCNT film as the channel material of the photo-detector. Among representative candidates of the PTE absorber: graphene, MoS_2, and PEDOT:PSS, the CNT film collectively satisfies ultrabroadband efficient photo-absorption ranging from Vis to MMW and macroscopic flexibility associated with high mechanical strength.

Based on these, this study first demonstrates that utilizing the CNT film-based PTE mechanism is suitable for realizing ultrabroadband photo-detection with sensitivities well comparable to that of existing solid-state narrowband devices. Thermoelectric conversion often employs the Seebeck effect at heterogeneous material junctions to enhance the effective Seebeck coefficients. Chapter 4 of this thesis evaluates the fundamental photo-detection performances of the CNT film PTE sensor by employing representative thermoelectric materials: bismuth and its compounds as the counterpart electrode of the channel. This chapter clarifies that the above coupling governs the photo-detection sensitivity of the device: 5–100 $pWHz^{-1/2}$ noise equivalent power (NEP) values in ultrabroadband photo-detection. These photo-detection sensitivities of the CNT film PTE sensor are well comparable to that of solid-state bolometers. Not only that, but the presenting thin-film device also maintains these performances regardless of the operating temperature and bending radius via optimal counterpart design.

Next, chapter 5 of this thesis demonstrates PTE conversion with pn-junction structures within the CNT film channel. This chapter clarifies that the channel properties govern the device sensitivity because the photo-detection interface: pn-junction comprises the CNT film itself. Together with a concentration optimization of the chemical dopant, which is necessary to form the n-type region, the above type of the CNT film PTE sensor also exhibits the minimum NEP value of 3.87 $pWHz^{-1/2}$. Moreover, the pn-junction structure device comprises fully soft materials and this situation eases the designing of stretchable PTE sensor array sheets. Chapter 6 introduces the partial rigid-soft patterning structure of the device sheet, and the CNT film PTE sensor array sheet allows the inherent photo-detection performances with up to 20 % NEP degradation against 70–280 % strains. By incorporating these findings and techniques, the presenting PTE device and system design lead to demonstrating broadband multi-wavelength and omni-directional photo-monitoring of composite and layered 3D objects in a non-destructive manner.