様　式　Ｃ－１９、Ｆ－１９－１、Ｚ－１９　（共通）

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研究課題名（和文）光学／ガンマ線ハイブリッド腹腔鏡の研究開発

研究課題名（英文）Optical/gamma hybrid laparoscope research and development

研究代表者
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研究者番号：９０８２４４６７

交付決定額（研究期間全体）：（直接経費）　　2,300,000円

研究成果の概要（和文）：この研究の目的は、腹腔鏡下がん手術中にセンチネルリンパ節（SLN）を視覚化できる新しい光学/ガンマ腹腔鏡を開発することである。このプロジェクトでは、2つの異なるモダリティ（1つはガンマカメラ、もう1つは光学イメージングシステム（蛍光+可視））を単一の腹腔鏡に統合して開発する必要がある。SLNファントムは、開発したガンマカメラを使用して明確に視覚化された。光学撮像部は、光学系の設計が終了した。今後、癌手術中のSLNマッピング用にハイブリッド光学/ガンマ腹腔鏡を開発する予定である。

研究成果の学術的意義や社会的意義
本研究の研究成果の学術的意義はガンマ線と光信号を同時に検出することができる小型装置の基礎研究である。ガンマ線検出器用の電子回路の小型化とコンパクト光学レンズのためガンマ／光学ハイブリッド腹腔鏡の実現が可能である。
本研究で開発された技術は腹腔鏡下がん切除の際にガンマ／光学イメージを同時に提供することでリンパ節の検出精度を改善できる可能性がある。

研究成果の概要（英文）：The goal of this study is to develop a novel hybrid optical/gamma laparoscope which can visualize the sentinel lymph node (SLN) during the laparoscopic cancer surgery. For this project, two different modalities, one is the gamma camera, and the other is optical imaging system (fluorescence + visible) should be developed an integrated into a single laparoscope. The gamma camera part was developed using tungsten pinhole collimator, GAGG scintillation crystal and SipM 8x8 array photo sensor. The SiPM signals were multiplexed by using a custom-made front-end electronics. The output of the front-end electronics were digitized by using CAMAC DAQ system. The SLN phantom filled with 99mTc solution was clearly visualized by using the gamma camera. For the optical imaging part, the optical system design was finished and the currently under development. In the near future, the hybrid optical/gamma laparoscope will be developed for SLN mapping during cancer surgery.

研究分野：医工学

キーワード：Laparoscope　Sentinel lymph node　Gamma imaging　Optical imaging

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様　式　C－１９、F－１９－１、Z－１９（共通）

１．研究開始当初の背景

In Japan, cancer is the number one cause of death. As Japan has entered super-aged society, early diagnosis and surgery of cancer are getting more important. For cancer surgery, the accurate detection and removal of sentinel lymph node (SLN) are quite important to minimize the recurrence probability of cancer after surgery. Recently, near-infrared (NIR) fluorescence image guided laparoscope cancer surgery has increased the detection rate of sentinel lymph node (SLN) during laparoscopic cancer surgery. However, NIR fluorescence image is effective only for the SLN located at the superficial of the tissues because of depth limitation (~10 mm) (Figure 1). In contrast, gamma image can visualize the SLN located deep tissues. Therefore, there have many demands for the hybrid NIR/gamma imaging system to improve the SLN detection accuracy which affects the patient outcome.

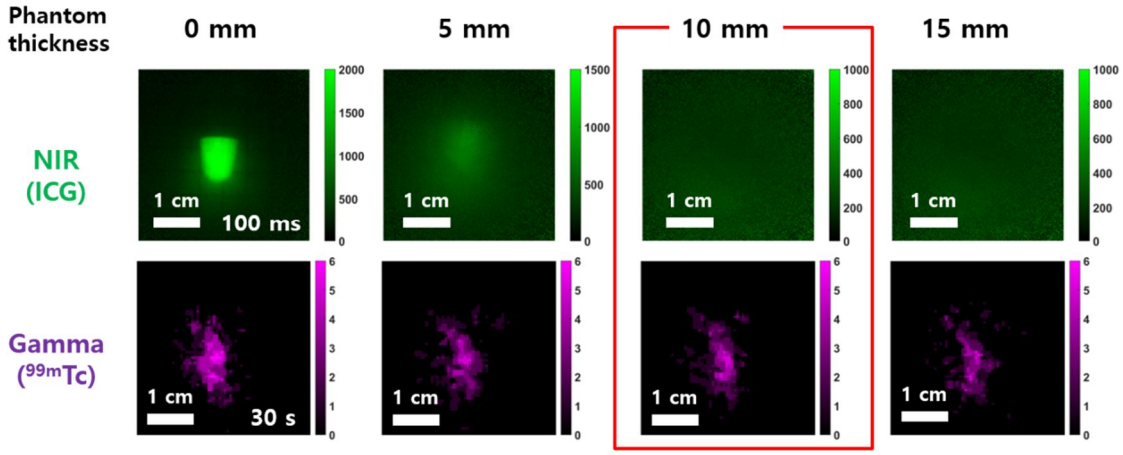

Figure 1. Comparison of tissue like-phantom penetration depths between NIR fluorescence and gamma photons (140 keV) (Experimental results).

２．研究の目的

The goal of this study is to develop a novel hybrid optical/gamma laparoscope which can visualize the sentinel lymph node (SLN) during the laparoscopic cancer surgery (Figure 2). In order to develop a hybrid laparoscope, the gamma camera and optical imaging system should be miniaturized and integrated together. One of the challenges in this project is the development of a compact gamma camera. Here we report the preliminary results of gamma camera imaging. The design of ultra-compact gamma camera is also presented.

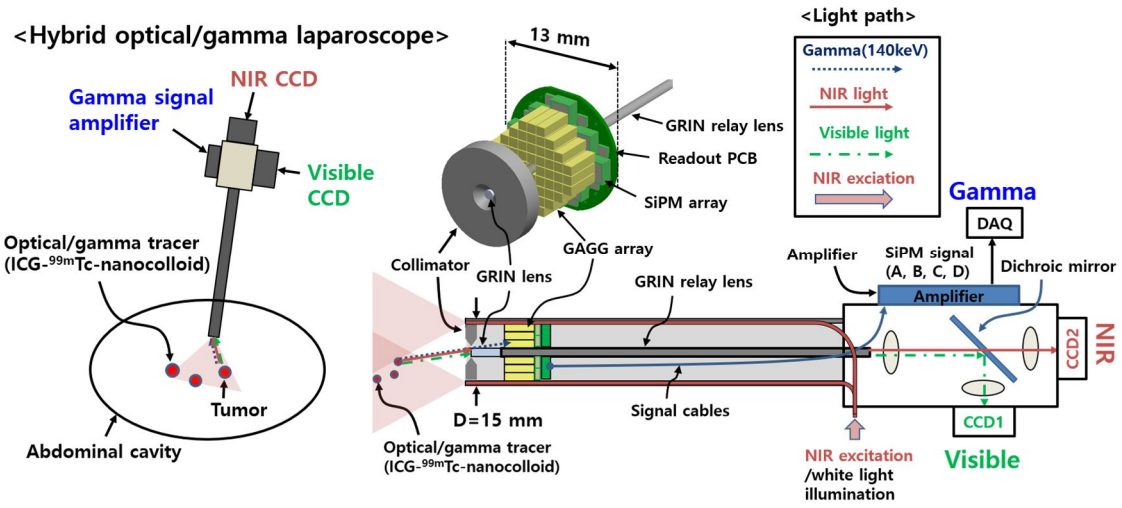

Figure 2. The proposed concept of hybrid optical/gamma laparoscope system (under development).

３．研究の方法

For the proof-of-concept study, we developed a gamma camera consists of tungsten pinhole collimator (aperture diameter = 2 mm) , GAGG scintillation crystal array (pitch=1 mm, length = 6 mm), SiPM 8×8 array and custom-made readout circuit (Figure 3). The 64 channel SiPM anode outputs were multiplexed into 4 positional signals to reduce the required data acquisition (DAQ) channels. The multiplexed SiPM signals were digitized by using CAMAC

DAQ.

For the gamma imaging, ^{99m}Tc filled Eppendorf tube which mimics SLN was used. The ^{99m}Tc phantom (1 MBq) was moved in x-direction with 30 mm step and gamma images were obtained for each ^{99m}Tc phantom position (figure 3). The 2D gamma images were generated after the calibrations of the detection efficiency non-uniformity and photo-peak non-uniformity.

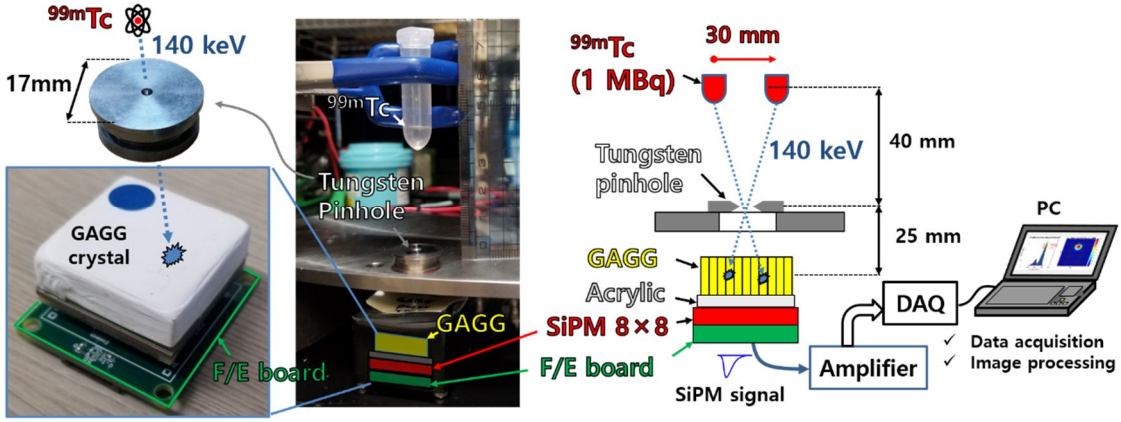

Figure 3. The developed gamma camera and experimental setup for the proof-of-concept of ^{99m}Tc SLN phantom imaging.

4. 研究成果

The energy resolution of the gamma camera was 14% and All the GAGG crystals were resolved in the flood map for ^{99m}Tc radioactive source (Figure 4). The 2D gamma images with two different ^{99m}Tc phantom positions (x=-15 mm, x= 15 mm) were obtained successfully (Figure 4).

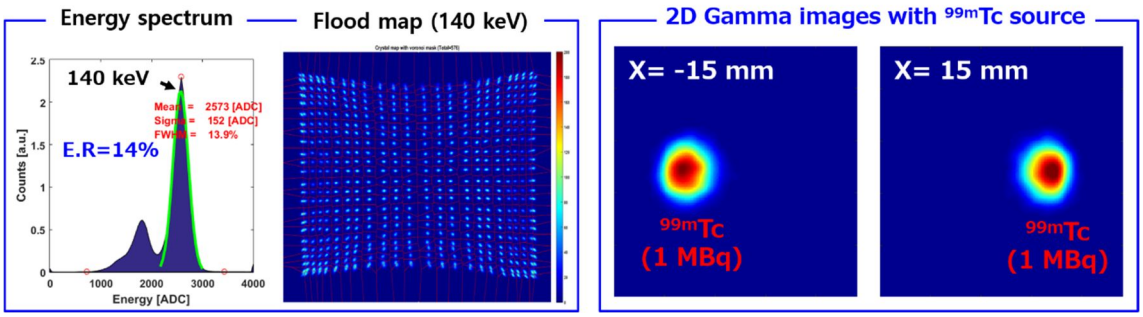

Figure 4. Energy spectra of the gamma camera before and after the photo-peak non-uniformity correction (left), flood map of the gamma camera with 140 keV gamma photon irradiation (right).

After the proof-of-concept study, we developed a new compact SiPM readout PCB having outer diameter of 13 mm (Figure 5). The center of the PCB has a hole with a diameter of 1.3 mm allowing the insertion of GRIN lens for optical imaging. The SiPM array will be soldered on the top side of the PCB and resistor network will be attached at the bottom side of the PCB. The hybrid optical/gamma laparoscope is under developed with the newly developed SiPM readout PCB

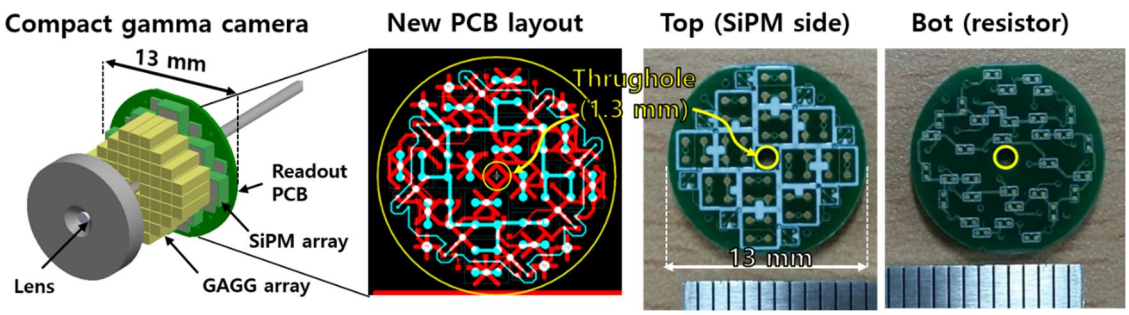

Figure 5. Compact gamma camera with the new readout PCB design for hybrid optical/gamma laparoscope.

５．主な発表論文等

〔雑誌論文〕　計1件（うち査読付論文　1件／うち国際共著　1件／うちオープンアクセス　0件）

１．著者名 Kang Han Gyu、Yamamoto Seiichi、Takyu Sodai、Nishikido Fumihiko、Mohammadi Akram、Horita Ryo、Sato Shinji、Yamaya Taiga	４．巻 64
２．論文標題 Optical imaging for the characterization of radioactive carbon and oxygen ion beams	５．発行年 2019年
３．雑誌名 Physics in Medicine & Biology	６．最初と最後の頁 115009～115009
掲載論文のDOI（デジタルオブジェクト識別子） 10.1088/1361-6560/ab1ccf	査読の有無 有
オープンアクセス オープンアクセスではない、又はオープンアクセスが困難	国際共著 該当する

〔学会発表〕　計1件（うち招待講演　0件／うち国際学会　1件）

１．発表者名 Han Gyu Kang
２．発表標題 Optical Imaging for the Energy Spread Estimation of Radioactive Oxygen Ion Beam - Experimental and GATE Simulation Results
３．学会等名 2019 IEEE NSS/MIC（国際学会）
４．発表年 2019年

〔図書〕　計0件

〔産業財産権〕

〔その他〕

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６．研究組織

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