Near-Field Terahertz Imaging of Ductal Carcinoma In Situ (DCIS) of the Breast

°(D)Kosuke Okada[1], Kazunori Serita[1], Quentin Cassar[2], Hironaru Murakami[1], Gaëtan MacGrogan[3], Jean-Paul Guillet[2], Patrick Mounaix[2], Masayoshi Tonouchi[1]

[1] ILE, Osaka Univ., [2] Univ. of Bordeaux, [3] Bergonié Inst.
E-mail: okada-k@ile.osaka-u.ac.jp

Terahertz (THz) imaging technique has been expected as a non-invasive/non-staining visualization tool for breast cancer margins during surgeries [1]. Breast cancer is a generic name for a heterogeneous lesion comprising invasive adenocarcinoma, in situ adenocarcinoma, most frequently in the form of ductal carcinoma in situ (DCIS) and benign tissues. Therefore, it is essential to identify the margins of the invasive carcinoma and DCIS for intraoperative breast cancer margin assessment. Until now, numerous THz imaging studies have focused on invasive adenocarcinoma. However, THz investigation of DCIS has hardly been conducted. One of the reasons is that the size of an individual DCIS lesion, ranging from 50 to 500 μm, is typically much smaller than that of an invasive carcinoma. This makes it difficult to detect these lesions by THz imaging, which has only a diffraction-limited spatial resolution of several millimeters.

To address this drawback, we have recently developed a "scanning point terahertz source (SPoTS) microscope" as a THz near-field imaging system without any sub-wavelength probes, as shown in Fig. 1. This microscope operates based on the near-field interaction between a sample and a point THz source. The sample is placed in the vicinity of a GaAs two-dimensional (2D)-THz-emitter crystal, and the point THz source is created at the irradiation spot of a 1.56 μm femtosecond pump pulse laser beam in the crystal via optical rectification. Because the localized THz wave pulses emitted from the source ($\phi_{\mathrm{THz}} \approx \phi_{\mathrm{Pump}}$) interact with the sample, THz spectroscopic imaging with a resolution close to the pump laser wavelength can be realized. Moreover, THz imaging measurement can be performed by 2D scanning of the point THz source (*i.e.*, pump laser pulse) over the GaAs crystal with a galvanometer. Indeed, transmission/reflection THz imaging at a spatial resolution of 20 μm $\approx \lambda_{\mathrm{THz}}$ / 34 (λ_{THz} = 680 μm) has been achieved [2,3]. In this study, utilizing the SPoTS microscope, we carried out near-field THz transmission imaging of a paraffin-embedded human breast cancer sample of 30 μm thickness containing DCIS and invasive ductal carcinoma (IDC), as a preliminary study.

Figure 2(a) shows the optical image of the THz-imaged sample. The sample is directly deposited on the GaAs crystal of 500 μm thickness. As can be seen in the corresponding hematoxylin-and-eosin (H&E)-stained image shown in Fig. 2(b), it contains the DCIS and IDC regions that are designated by purple and blue dotted lines, respectively, and fibroadipose (benign) tissues correspond to the orange/pink-stained areas that fill the gaps between the malignant structures. Figure 2(c) presents the THz transmission image of the sample shown in Fig. 2(a). We succeeded in discriminating the three regions of DCIS, IDC, and fibroadipose tissue on a micrometer scale, in good agreement with the H&E image of Fig. 2(b) [4]. In addition, it was also found that the THz attenuation was significantly different for DCIS and IDC; the details will be discussed. These can be caused by the interaction between the THz waves and the cellular density. Therefore, the results indicate that the SPoTS microscopy may open the route to THz intraoperative diagnosis to accurately assess DCIS margins.

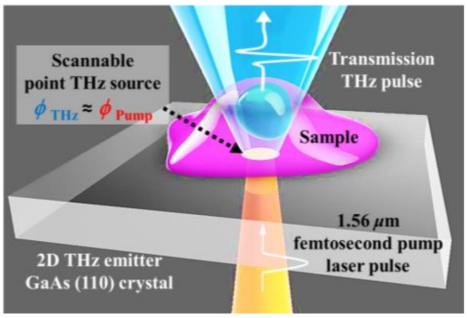

Figure 1. Schematic of the scanning point terahertz source (SPoTS) microscope

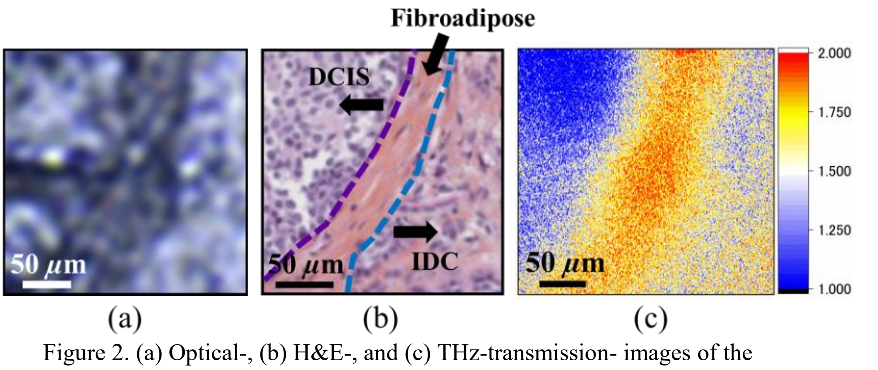

Figure 2. (a) Optical-, (b) H&E-, and (c) THz-transmission- images of the paraffin-embedded human breast cancer sample containing DCIS and IDC.

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