Resolution Measurement of a 2.52 THz Continuous-Wave Terahertz Scanning Imaging System

Yun-Da Li, Qi Li, Sheng-Hui Ding, Qi Wang
National Key Laboratory of Science and Technology on Tunable laser
Harbin Institute of Technology
Harbin, China
liyunda_hit@yahoo.cn

***Abstract*—The resolution of a terahertz scanning imaging system based on a CO_2 pumped continuous-wave terahertz laser at 2.52 THz was measured. A self-made resolution test chart was employed and scanned. The imaging results show that the system's resolution is 0.6 mm. The experiment results are also compared with the results of another point-by-point scanning imaging system. The study can make a contribute to the development and application of THz imaging technique.**

Keywords-Terahertz imaging; scanning imaging; resolution

I. INTRODUCTION

Over the past several years, the wide applicability of terahertz (THz) imaging in areas such as biomedical science [1], non-destructive evaluation [2], and security control [3, 4] has driven the development of THz imaging systems with high-resolution and large dynamic range. Most existing THz imaging systems are based on the scanning mechanism. Compared with 2D imaging systems, the scanning mechanism can offer a larger dynamic range and signal-to-noise ratio (SNR) while the imaging speed is slower. Moreover, unlike 2D imaging systems in which the imaging resolutions are constrained by diffraction effects, the imaging resolutions can be improved by constraining the scanning beam spot. Because THz imaging are usually used for concealed objects imaging, the THz radiation would suffer great attenuations caused by materials such as clothing and plastics, high penetration capability is required for those applications [3~6].

Optically pumped continuous wave (CW) THz laser was firstly used in THz scanning imaging technique [7]. With the development of THz technique, a remarkable progress such as the improvement of the output power, stability, reliability, and system volume has been made in the development of optically pumped CW THz laser. Those advantages make optically pumped THz laser an ideal light source for investigation into THz imaging technique. Mohammed Salhi et al. demonstrated their study on the confocal imaging using a CO_2 pumped THz laser at 2.52 THz [8-9]. They transferred the principle of the optical confocal microscope to a far-field THz imaging system, thus improving the imaging resolution. The image resolution was improved to 0.31 mm at 2.52 THz. However, the confocal setup requires the insertion of two confocal pinholes which would reduce the illumination power. Peter H. Siegel et al. applied a CO_2 pumped THz laser to biomedical fields for heterodyne imaging [10]. The dynamic range could reach more than 100 dB. However, the heterodyne scheme requires two coherent THz sources which are costly. Jason C. Dickinson et al. built a spot scanner system based on two CO_2 pumped THz lasers and THz heterodyne detection systems [11]. Qi Li et al. designed a CW THz point-by-point scanning imaging system and a series of concealed objects were scanned. The results showed that the resolution of the system was 0.4mm [12, 13].

As the samples used in transmission-mode THz scanning imaging always have certain thicknesses, and sometimes they can not be correctly placed in the focal plane, it is necessary to make sure that the beam diameter is small enough and the diameter of the beam does not change a lot within some distance. Thus, in the paper, a transmission-mode THz scanning imaging system was designed and constructed based on a CO_2 pumped THz laser. To study the system's imaging capability, a self-made resolution test chart was scanned for resolution measurement, and the results were compared with the ones of the imaging system in Ref. [12, 13].

II. 2D SCANNING IMAGING SYSTEM

In order to reduce the energy losses and raise the system's penetration ability, off-axis parabolic mirrors (OAPM) were adopted here instead of polyethylene lenses. This displacement greatly reduced transmission losses and made it convenient to use the He-Ne laser to help alignment. The THz source is a CO_2 pumped CW laser SIFIR-50 from Coherent Inc. The laser was operating at 2.52 THz, with CH_3OH as the working gas. The average output power is about 50 mW. The spatial mode of the laser output at 2.52 THz is EH_{11} mode which is linear polarized. A pyroelectric

camera Pyrocam III from Ophir-Spiricon Inc. was used for imaging beam profile. The measured diameter of the beam waist is 3.4 mm, and the divergence angle is 2.5°. The detector used for power measurement is P4-42 from Molectron Inc. It is a $LiTaO_3$ pyroelectric detector and has a relative high responsivity, which promises the high dynamic range of the image system. The output voltage was collected by a data capture card connected to the computer. It can be turned to different detectable range levels. Different levels correspond to different minimal and maximal detectable voltages.

The imaging system was designed according to the Gaussian beam assumption. To fully utilize the laser output and reduce energy loss, the imaging system was designed to work in transmission mode, which is schematically depicted in Fig. 1. Light emitted from SIFIR-50 converge with a He-Ne laser at a high-resistivity silicon wafer and then is expanded by a pair of OAPMs M1 and M2. The effective focal lengths of the OAPMs are about 5 cm and 10 cm. Then light is focused on the target by another OAPM M3 with a large focus length (~15cm). Light transmitting through the target is collected and focused onto the detector by another pair of OAPMs M4 and M5. The effective focal

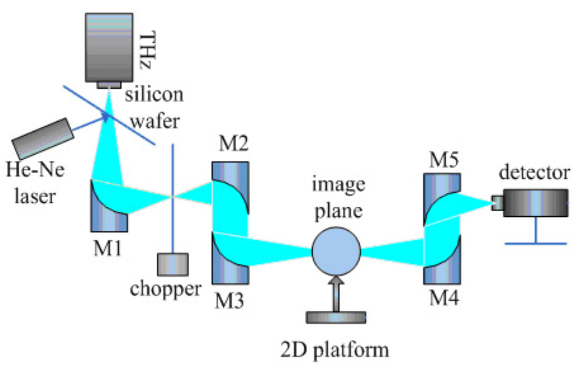


Figure 1. Schematic diagram of THz scanning imaging setup.

lengths of them are 10.16 cm and 5.08 cm, respectively. The total length of the optical path for the system is about 76 cm. And the theoretical spot diameter at the imaging plane is 0.86 mm according to the Gaussian beam assumption. The target is mounted on a 2D platform. The control of the imaging process is accomplished by a self-designed VC program.

III. RESOLUTION TESTS

According to Rayleigh criterion, the maximum value for the ratio of the signal minimum to signal maximum is set 0.811 in the case of an acceptable resolution. A resolution chart is used to test the system's resolution. The charts are Teflon substrate printed circuit boards with metallic strip arrays of different strip widths (shown in Fig. 2). The thickness of the Teflon substrate is 1.5 mm, and the spaces between the strips are 0.6 mm, 0.4 mm, 0.3 mm, 0.2 mm and 0.15 mm, respectively.

The resolution test chart is shown in Fig. 2, and the 0.3 mm-width, the 0.4 mm-width and the 0.6 mm-width strips were scanned respectively. The scanning step lengths were set to 0.1 mm and 0.2mm, respectively. The delay time for each pixel was 500 ms.

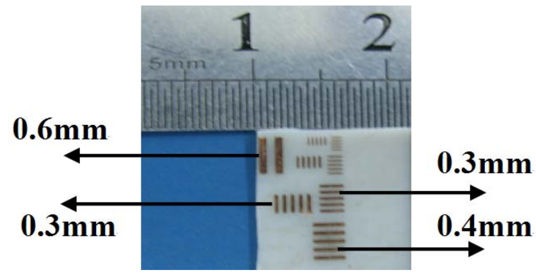
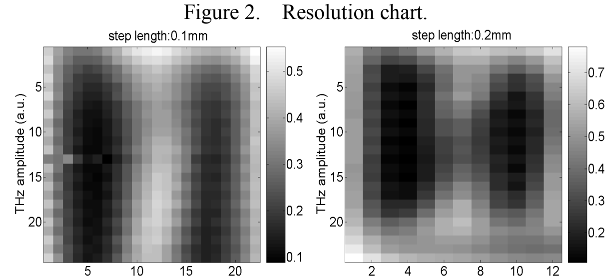
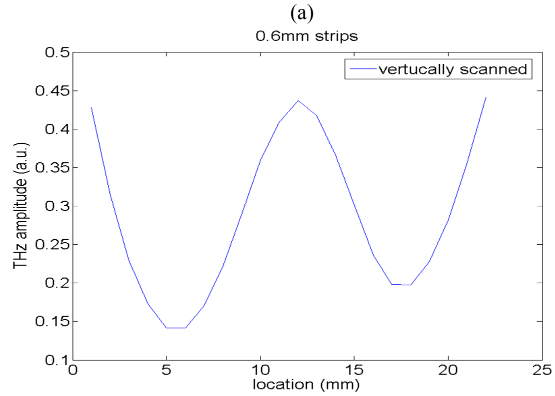


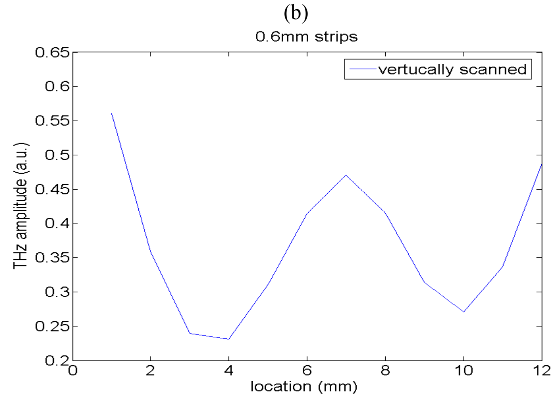
Figure 2. Resolution chart.



(a)



(b)



(c)

Figure 3. Resolution test results and scanning step lengths: (a)0.6 mm-width strips; (b)step length:0.1mm; (c)step length:0.2 mm.

Before reaching the object, the laser's output was attenuated severally by 7 pieces of paper (transmittance 0.43 for one piece, so 25.7 dB attenuation in total) and 5 pieces

of paper (18.3 dB attenuation in total) when the step length was set 0.1mm and 0.2mm. Several lines of the scanning results were averaged to reduce the influence of noise. The imaging results are shown in Fig. 3(a). The averaged line scans of the detector's output voltage (in proportion to the THz intensity reaching the detector) are shown in Fig. 3(b) and Fig. 3(c). The ratio for the vertical line scan result of 0.6 mm strips is 0.4519 while the scanning step length is 0.1mm, and the result is 0.5752 while the scanning step length is 0.2mm. According to Rayleigh criterion, those strips can be well resolved.

In Fig. 3 we can see the voltages of the two metallic strips aren't equal, the reason is that the left strip is on the edge of the resolution chart and we can see that in Fig. 2(b). There will be additional attenuation for THz radiation caused by scattering, so the voltage of the right metallic strip is higher.

To further study the system's resolution, strip arrays comprised of 0.4 mm-width strips were scanned. The scanning results are shown in Fig. 4. When the sample is placed horizontally, the maximal and minimal voltage can not be distinguished.

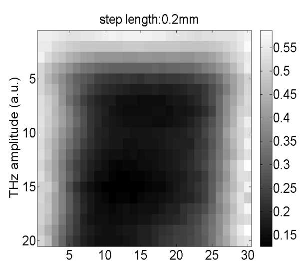


Figure 4. Resolution test results: horizontal strips: 0.4 mm.

IV. RESULTS COMPARISION

A similar scanning imaging system in transmission-mode is presented in [12, 13]. The imaging setup is similar to the setup in Fig. 1. The effective focal lengths of the first three OAPMs are about 10cm, 15cm and 5cm, respectively. The resolution charts are shown in Fig. 5, and the 0.6 mm-width, 0.4 mm-width and 0.2 mm-width strips were scanned.

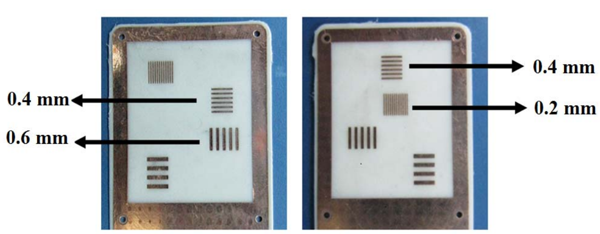


Fig. 5 Resolution charts, strips width:0.2mm,0.4mm and 0.6mm.

The scanning results and the line scans of the detector's output voltage are shown in Fig. 6. The ratio for the horizontal line scan result of 0.6 mm strips is 0.176, and the result for the vertical line scan is 0.05. According to Rayleigh criterion, those strips can be well resolved. For the 0.4 mm strips, the ratio of the minimal voltage to the maximal voltage of the horizontal line scan is 0.485, and the result for the vertical scan is 0.275. Those values all satisfy the Rayleigh criterion. Therefore, it can be concluded that the system's resolution can reach at least 0.4 mm in both directions.

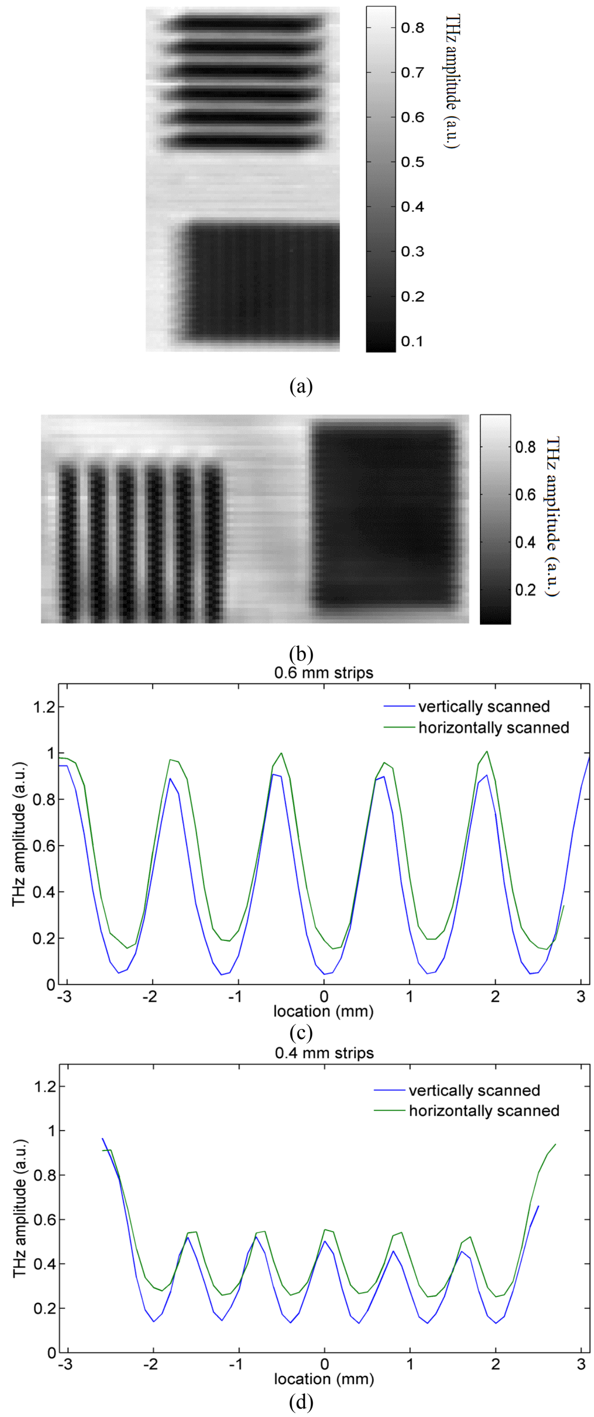


Figure 6. Resolution test results and line scans of the strips: (a)horizontal strips: 0.4 mm, vertical strips: 0.2 mm; (b)horizontal strips: 0.2 mm, vertical strips: 0.4 mm; (c)0.6 mm strips; (d)0.4 mm strips.

The scanning results of the strip arrays comprised of 0.2 mm-width strips are shown in Fig. 6. When the sample is placed horizontally, the ratio of the minimal voltage to the maximal voltage is 0.86. According to Rayleigh criterion, the strips are regarded almost unresolved. When the sample is placed vertically, the maximal and minimal voltage can not be distinguished. From those results, it can be determined that the system's resolution is between 0.2 mm and 0.4 mm both horizontally and vertically.

By comparison we can see that the resolution in [12, 13] is higher than the result we obtain. But as we have discussed above, the imaging targets used always have certain thicknesses, thus a small divergence angle is needed to minish the beam diameter change along the transmitting direction. Via calculating the divergence angle in the paper is about 10.1°, and the value for the system depicted in [12, 13] is approximately 22.7°. Obviously there will be much more changes in beam diameters when the samples have unneglectable thicknesses or they are placed a little far away from the focal plane. The errors are inconvenient and will directly affect the real resolution during experiments.

V. CONCLUSION

In conclusion, the resolution of a CO_2 pumped 2.52 THz transmission-mode scanning imaging system was measured. The imaging results of the resolution chart exhibit that the system has a resolution which can reach at least 0.6 mm. It has been approved that the imaging system is more suitable for imaging application of samples with certain thicknesses while the resolution decreases. The study is expected to promote the development and application of THz imaging technique.

REFERENCES

[1] E. Pickwell, and V. P. Wallace, "Biomedical applications of terahertz technology," J. Phys. D: Appl. Phys., vol. 39, pp. R301-R310, 2006.

[2] V. P. Wallace, E MacPherson, J. A. Zeitler, and C. Reid, "Three-dimensional terahertz radiation," J. Opt. Soc. Am. A, vol. 25, pp. 3120-3133, 2008.

[3] J. F. Federici, B. Schulkin, F. Huang, D. Gary, R. Barat, F. Oliveira and D. Zimdars, "THz imaging and sensing for security applications-Explosive, Weapons, and Drugs," Semicond. Sci. Tech., vol. 20, pp. S266– S280, 2005.

[4] Q. Song, Y. Zhao, A. Redo-Sanchez, C. Zhang, and X. Liu, "Fast continuous terahertz wave imaging system for security," Opt. Comm., vol. 282, pp. 2019–2022, 2009.

[5] A. J. L. Adam, P. C. M. Planken, S. Meloni, and J. Dik, "Terahertz imaging of hidden paint layers on canvas," Opt. Express, vol. 17, pp. 3407–3416, 2009.

[6] S. Wang and X.-C. Zhang, "Tomographic imaging with a terahertz binary lens," Appl. Phys. Lett., vol. 82, pp. 1821–1823, 2009.

[7] T. S. Hartwick, D. T. Hodges, D. H. Barker, and F. B. Foote, "Far infrared imagery," App. Opt., vol. 15, pp. 1919-1922, 1976.

[8] M. Salhi, M. Koch, "Semi-confocal imaging with a THz gas laser," Proc. of SPIE 6194, 6194A, (2006).

[9] M. A. Salhi, I. Pupeza, and M. Koch, "Confocal THz Laser Microscope," J. Infrared Milli. Terahz. Waves, vol. 31, pp. 358-366, 2010.

[10] P. H. Siegel and R. J. Dengler, "Terahertz heterodyne imager for biomedical applications," Proc. of SPIE, vol. 5354, pp. 1–9, 2004.

[11] J. C. Dickinson, T. M. Goyette, A. J. Gatesman, C. S. Joseph, Z. G. Root, R. H. Giles, J. Waldman, and W. E. Nixon, "Teraherz imaging of subjects with concealed weapons," Proc. of SPIE, vol. 6212, pp. 62120Q, 2006.

[12] Li Qi, Yao Rui, Ding sheng-hui, Wang Qi, "Experiment on 2.52 THz transmission-mode imaging for concealed objects," Chinese J. Lasers, Vol. 38, pp. 071100, 2011.

[13] Yao Rui, "Experimental research on the improvement of CW-THz 2D imaging quality and speed," Dissertation for the Master Degree, pp. 24-26, 2010.