Sub-terahertz Imaging for Construction Materials

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***Abstract*—Sub-terahertz imaging for construction materials has been performed using room-temperature operating oscillators. Invisible defects in woods, and mixed foreign bodies and cracks in concrete were detected effectively by power transmission imaging. In addition, rusty area covered with paint on the steel was distinguished by power reflection imaging. So, Sub-terahertz imaging is one of the promising tools for the safe structural engineering.**

I. Introduction And Background

Sub-terahertz-wave has a permeable characteristic for many kinds of materials, therefore it is a promising selection for nondestructive inspection with no hazard to human being. On the other hand, sub-THz sources using optical devices need laser systems which are difficult to reduce sizes and prices. So, a compact light source by electron device with high stability of frequency and output power is desired. We have developed a room-temperature operating low-noise oscillator based on transit-time delay of tunneling injection of electrons (TUNNETT) with continuous-wave and fundamental-mode in the range from 40 to 700 GHz [1, 2]. We have demonstrated sub-THz imaging using TUNNETT for the inspection of biomaterials [3, 4]. In this paper, we show the performance of inspection for construction materials, i.e. wood, concrete, and painted steel lumber.

II. Results

A. Characteristics and imaging of wood

The electro-magnetic waves emitted from TUNNETT are highly polarized, the transmitted power of wood materials depends on the fiber direction of cellulose as shown in Fig. 1. When the electric field of sub-THz wave was oriented longitudinal to the direction of cellulose fibers of wood, the absorption coefficient was 1.5 times higher than the case of the wave oriented transverse.

The absorption coefficients of various kinds of woods at sub-THz range were approximately proportional to the density of woods among the different species with exception of chestnut-lumber as shown in Fig. 2. This may be reasonable, because the most of components of woods are similar as cellulose, hemicelluloses, and lignin. The density difference of wood will come from the cell-wall volume ratio [5].

Water content is another important factor of woods. We have demonstrated the absorption coefficient of 200 GHz-wave from TUNNETT with different water content of wood blocks. The power transmission changes exponentially, the water content measurement with sub-THz can be very sensitive.

Detection of invisible defects in wood blocks has been performed effectively by power transmission imaging for invisible knots which are local circle grains, and invisible hole in a few mm-scale as shown in Fig. 3. Considering the wide range of TUNNETT fundamental-mode CW operation from 40 to 700 GHz, sub-THz imaging can be used as a tool for the non-destructive evaluation of wood up to 10 cm-thick at least.

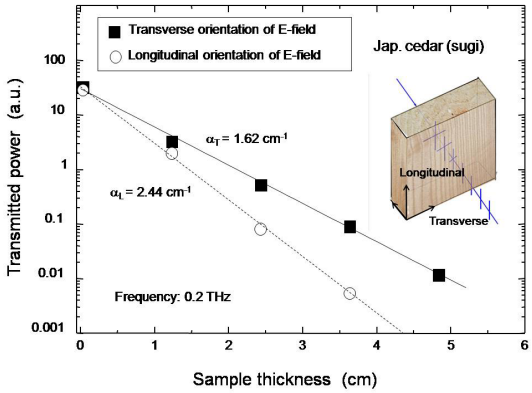

Fig. 1 Transmittance of wood using polarized 0.2 THz-wave from TUNNETT.

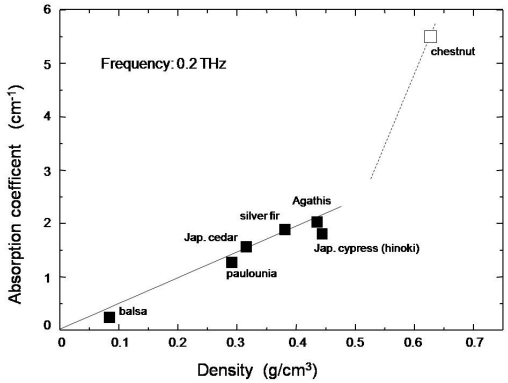

Fig. 2 Absorption coefficients of various woods versus the density of woods.

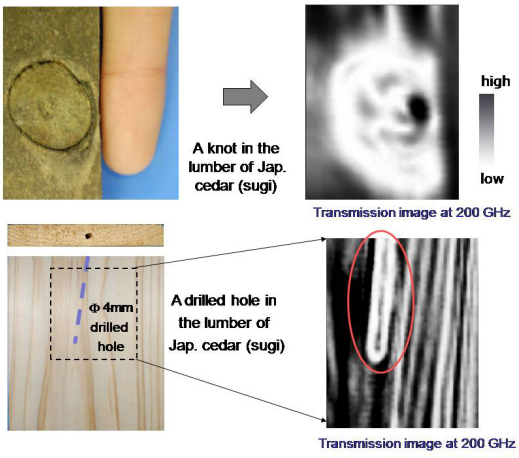

Fig. 3 Transmission imaging of defects in wood block using 200 GHz-wave.

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B. *Transmission imaging of concrete*

In the case of concrete materials, the higher frequency of sub-THz wave shows a drastic decrease of the transmittance than the case of wood materials as shown in Fig. 4. The maximum thickness of concrete block was 60 mm at 50 GHz, and 40 mm at 70 GHz, when we use 10 mW output oscillators and room-temperature operating Schottky barrier diode detector (SBD). The penetration depth will be improved about 40% when we use 4.2 K Si bolometer which has 2 order lower minimum detectable power-levels than the one of SBD. Fig. 5 shows the transmission imaging of concrete blocks with 25 mm thick, which included metal-plate, and wood piece and cardboard piece, using 67 GHz oscillator. The images show the mixed foreign bodies clearly with a few-mm resolution. This method has been demonstrated successfully to detect the narrow cracks about 0.3 mm void-space, and hidden cracks near the surface.

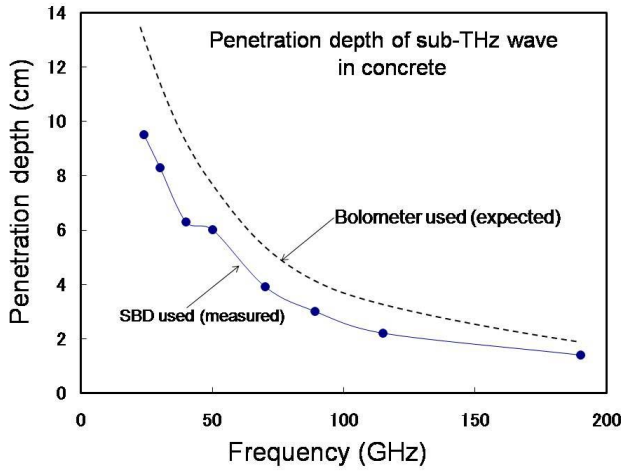

Fig. 4 Penetration depth of sub-THz-wave in concrete when 10 mW oscillators and SBD detector were used (solid line), and 4.2 K bolometer used (dashed line).

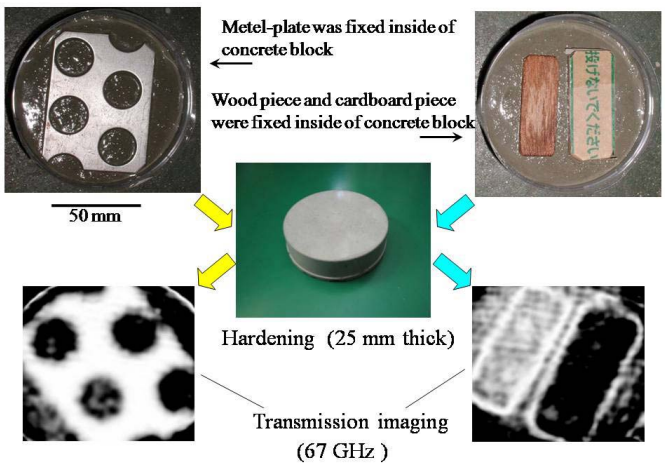

Fig. 5 Transmission imaging of concrete blocks using 67 GHz-wave. The brocks included metal-plate, wood piece, and cardboard piece inside of the body, and hardened before measurement.

C. *Reflection imaging of painted steel lumber*

A steel material has no transmittance for electro-magnetic wave, however, by using reflection imaging of sub-THz wave, the surface figure which is hidden under the coating is detectable.

Up to now, THz imaging has been demonstrated as point scan method by scanning the sample in many research institutes. These methods have a big disadvantage for imaging of huge objects. We developed a probe-scan method for reflection imaging with compact-system scan instead of the sample-scan.

We have demonstrated sub-THz reflection imaging of a painted steel lumber which was rusty partially as shown in Fig. 6. The sub-THz wave penetrated through the painted layer, and reflected on the steel surface. The reflection image obtained shows rusty area clearly, on which the reflection power is reduced by scattering. This shows sub-THz nondestructive inspection is applicable even for the steel materials.

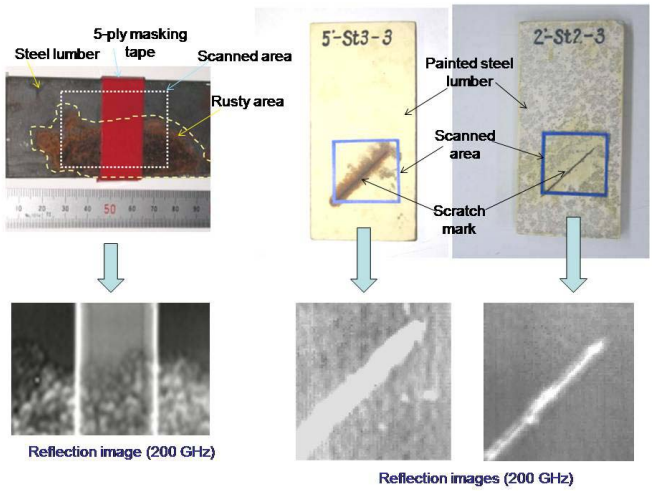

Fig. 6 Reflection imaging of rusty steel lumber covered with 0.85 mm-thick masking tape partially, and weathered painted-steel lumber with scratch mark , respectively, using 200 GHz-wave.

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