

# Identification of Textile Fiber by Terahertz Spectroscopy

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**Abstract—** We developed a novel differentiation technique for most textile fibers using terahertz (THz) transmittance spectroscopy. As demonstrations, several kinds of plant-derived fibers, animal fibers, and artificial fibers were milled at 77K, and were examined by THz spectroscopy in the range from 0.5 to 6.2 THz. Absorption spectra of a majority of textile fibers are distinguishable by THz spectroscopy, even for fibers in the same category or species. The advantage of this technique is its sensitivity to the structural differences of the textile fibers, even if they consist largely of the same components.

## I. INTRODUCTION AND BACKGROUND

The adulteration of pure cashmere-goat hair with foreign fibers has now become common and is one of the latest mislabeling problems that confronts the textile industry world-wide. For an assay certificate, the cuticle scale patterns of the hairs are currently observed under the microscope by experts, and cashmere fiber must be counted and differentiated from other animal hair and artificial fibers to verify the declared mixing rate—a very labor-intensive process that is not fully reliable because some types of animal hair which look similar to cashmere [1]. In addition, the technique of extracting DNA from animal hair and amplifying it prior to analysis is difficult because hair contains very small amounts of DNA, and the DNA is easily destroyed by scouring, bleaching, or dying [2]. Therefore, the textile industry is searching for a simple, rapid, and reliable method to identify textile fibers.

Although the new technology of terahertz-wave transmission has been used for clothing inspection, its use to identify textile fibers is rare, with the exception of several previous studies on “artificial” polymers [3]. In a pioneering work, we demonstrated the use of terahertz (THz) spectroscopy for identifying several types of plant-derived fibers, animal fibers, and artificial fibers using a widely tunable THz spectrometer [4]. This spectrometer can sweep over a frequency range from 0.5 to 6.2 THz with a line-width of 3 GHz; measurements were performed in 15- or 20-GHz steps.

Whereas the only transitions that are usually observed in infrared spectrum are intra-molecular vibrational modes, many different types of transitions are sufficiently low energy that they occur in the THz region [5]. For organic compounds, they include intermolecular stretching modes involving heavy atoms, skeletal bending modes, torsional mode, and hydrogen bond stretching, in addition, crystal lattice modes in THz region. The spectra of textile fibers can be used as a *fingerprint* for identification of the materials.

## II. RESULTS

To prevent thermal alteration during processing, the sample

fibers used in the present study were grinded into particle at 77 K with a mixer mill. The grain size of the resulting powders for plant-derived fibers and animal fibers is less than 10  $\mu\text{m}$ , and for artificial fibers the size is several tens of microns. These sizes of the sample are smaller than the wavelength of the analyzing radiation, which is desirable to avoid light scattering from the samples. For THz spectroscopy, each sample of homogeneous milled powder was mixed with fine polyethylene, and was pressed to form pellets containing 2.5 to 10 wt% of the target material.

### A. Identification of synthetic fibers

As shown in Fig. 1, the absorption spectra of the synthetic fibers acrylic, polyester, nylon 6, nylon 6/6 show specific peaks respectively. Especially, nylon 6 exhibits remarkable absorption peaks at 2.0 and 3.1 THz, whereas nylon 6/6 has remarkable peaks at 2.0, 3.3, and 5.1 THz. Thus, the spectra of the two different nylons are clearly differentiated by THz spectroscopy, whereas the spectra of nylons are indistinctive by infrared spectroscopy because of the similar spectra of them [6]. These results indicate that the skeletal bending or torsional modes of synthetic polymers are distinguishable between polyester, acrylic and nylons.

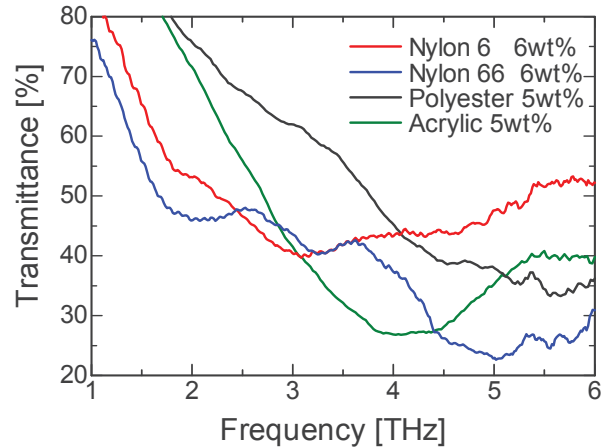


Fig. 1 Absorption spectra of synthetic-fibers, nylon 6, nylon 6/6, polyester and acrylic fibers.

### B. Identification of plant-derived fibers

The absorption spectra of plant-derived fibers and a regenerated cellulose fiber are shown in Fig. 2. The remarkable absorption peaks of cotton occur at 2.1, 3.2, 4.3, and 5.2 THz, which almost fits the spectrum of reagent cellulose which

crystallizes in a monoclinic system. The spectra of hemp, linen, and ramie exhibit spectra that are similar to that of cotton, but the shape and intensity of the peaks at 3.2 and 5.2 THz in each sample are quite different. The spectrum of rayon, which is classified as a regenerated cellulose fiber, has a profile similar to that of cellulose but much weaker. The spectrum of rayon indicates that the crystalline forms of cellulose have almost disappeared because of the wet fiber-forming process of the crystalline material. These results show that THz spectroscopy can clearly differentiate between the different cellulose structures in each cellulosic fiber.

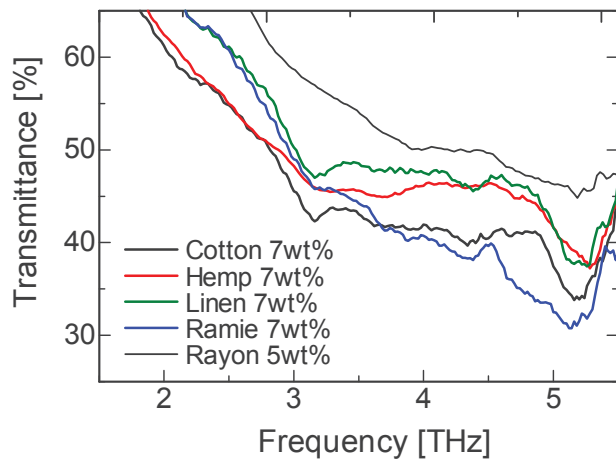


Fig. 2 Absorption spectra of plant-derived fibers of cotton, Hemp, Linen, Ramie at 7wt%, and a regenerated cellulose fiber Rayon at 5wt%.

### C. Identification of animal hairs

The THz spectra of the pure animal hairs of Cashmere-goat, Merino-sheep, Yak-bovine, and camel are shown on a semi-log plot in Fig.3. In conventional assay certificate, it is sometimes difficult to differentiate cashmere fiber from fine sheep wool and fine Yak underhair. Merino-sheep hair is characterized by its extreme fineness; its average fineness is 16–18  $\mu\text{m}$  whereas that of cashmere is 11–18  $\mu\text{m}$ . The average fineness of Yak is 18–19  $\mu\text{m}$ , and the one of camel is 9–20  $\mu\text{m}$  in a similar size with the one of cashmere.

The spectra of cashmere, Merino, and Yak exhibit broad absorption peaks, but the characteristics of each specimen are different from each other. The spectrum of cashmere has a discriminative absorption at 4.7 THz, and they can be differentiated from the other animal hairs because the Merino-sheep spectrum shows remarkable absorption at 3.9 THz, the Yak-bovine spectrum has dominant peaks at 5.2 and 5.7 THz, and the camel hair spectrum has specific absorption at 4.1 and 4.9 THz.

Animal-hair fiber is almost 100% protein, and is composed of the cuticle, the medulla, and the cortex. All animal-hairs bear morphological characteristics typical to the family of the particular species. The morphological characteristics are seen on the outside of the hair as cuticular scale patterns, and inside the cortex as medullary patterns. The cortex, which takes the

form of either ortho or para-cortex, consists of keratin protein, and constitutes approximately 90% of the hair structure, and is produced in hair follicles in spindle-shaped epithelial cells with intercellular materials. The vibrations related cortex as intra-molecule mode may be detectable by THz spectroscopy, although no difference is observed in intra-molecule vibrations of hair protein by infrared spectroscopy [6].

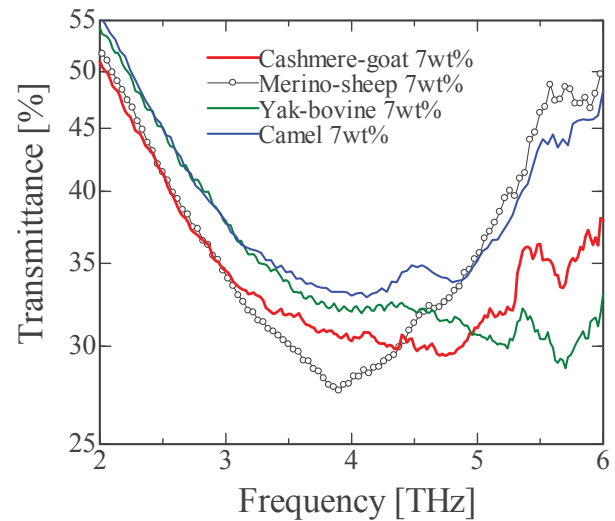


Fig. 3 Absorption spectra of Cashmere-goat, Merino-sheep, Yak-bovine, and camel as animal hairs. The transmittance of the longitudinal axis was used logarithmic display to enhance the difference of each spectra.

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