# The effect of the moisture condition of bulk wood on transmitted output power from a semiconductor near infrared laser

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## Introduction

Near infrared (NIR) spectroscopy is a useful method for the detection of physical and chemical conditions of biological material having a cellular structure, such as wood.[1–5] To find the wide applications of NIR to wooden articles, we tried to construct a high-powered measurement system in which the measurable sample thickness is larger than that of the traditional apparatus. Then, we looked at constructing a practical, non-destructive measurement system with a semiconductor near infrared laser, with which some information from thicker wood samples could be obtained. A series of experiments were carried out giving attention to some geometrical conditions of illumination (incident angle, etc.) and physical conditions (sample thickness, direction of fibre, etc.).[6] As a result, the optical penetration length outstandingly exceeded the traditional spectrophotometer. Furthermore, it was revealed that the transmitted output power through wood samples, *Pt*, varied characteristically with the combination of geometrical conditions of illumination and physical conditions of a sample. In this way, the semiconductor near infrared laser system may exhibit lively performance for the nondestructive measurement of wooden articles.

It is important for the non-destructive measurement of wood to measure the moisture condition correctly.[7,8] In this study, we gave attention to the applicability of the semiconductor near infrared laser to such a problem. The semiconductor near infrared lasers using the wavelength of 830 nm, which did not directly relate to water absorption and 980 nm, which was assigned to water absorption, were employed. Here, two series of experiments were carried out. First, *Pt* of Sitka spruce, which were humidified ranging from oven-dried state to fibre-saturation state, were measured. Second, the wood sample containing free water was dried indoors and *Pt* was measured at the required interval.

In this study, we gave attention to the NIR laser as a concrete nondestructive measurement device. Using this system, the internal information of a wood sample may be detected. We collected the basic data necessary to put an in-process measurement system to practical use.

## Experimental

### Measuring apparatus

The measuring system is shown in Figure 1. This apparatus is composed of the semiconductor NIR laser (LT015MD, SHARP Co.), the sample holder and the thermocouple power meter (PM-311DA,

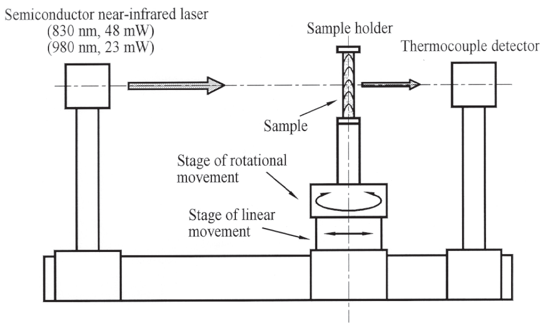


**Figure 1. Outline of measuring system.**

Nihon Kagaku Engineering Co.), which are held on a optical bench. The sensing head of the thermocouple power meter had a 16 mm diameter. In this study, the semiconductor near infrared lasers using wavelengths of 830 nm and 980 nm were employed. Their output power was 48 mW and 23 mW, respectively. The beam diameter was 3 mm. The distance between the sample and the detector was set at 2 mm or 9 mm.

### Samples

The samples used were Sitka spruce (*Picea sitchensis* Carr.) having the oven-dried density of 0.45 $gcm^{-3}$. Each sample was microtomed and was both 25 mm long and wide. The irradiation surface of a sample corresponded to the edge grain and the incident angle was 0º.

### Experiments

The main purpose of this study is to assess correctly the relationship between the transmitted output power *Pt* and the moisture in the wood sample. The water in the wood sample is mainly divided in to the adsorptive water and the free water. Their effect on the physical and mechanical properties of wood varies characteristically with their circumstances.[7,8] Then we investigated the response of *Pt* for the adsorptive water and the free water, respectively.

In this study, two series of experiments were carried out. First, *Pt* from specimens humidified ranging from an oven-dried state to fibre-saturation state were measured. Second, the wood sample containing free water was dried indoors (23°C and 45% RH) and *Pt* was measured at the required interval.

## Results

### Effect of adsorptive water on transmitted output power

Figure 2 shows the variation of *Pt* with moisture content not more than fibre saturation point at each sample thickness, *d*. In these figures, white and black circles indicate *Pt* at $\lambda$ = 830 nm and $\lambda$ = 980 nm, respectively. The correlation coefficient between moisture content and *Pt* for each wavelength is illustrated in Figure 3:

***In the case of $\lambda$ = 830 nm***

It can be seen from these figures that the positive correlation between moisture content and *Pt* for $\lambda$ = 830 nm decreases rapidly with increased *d*. There is no direct relationship at this wavelength on the

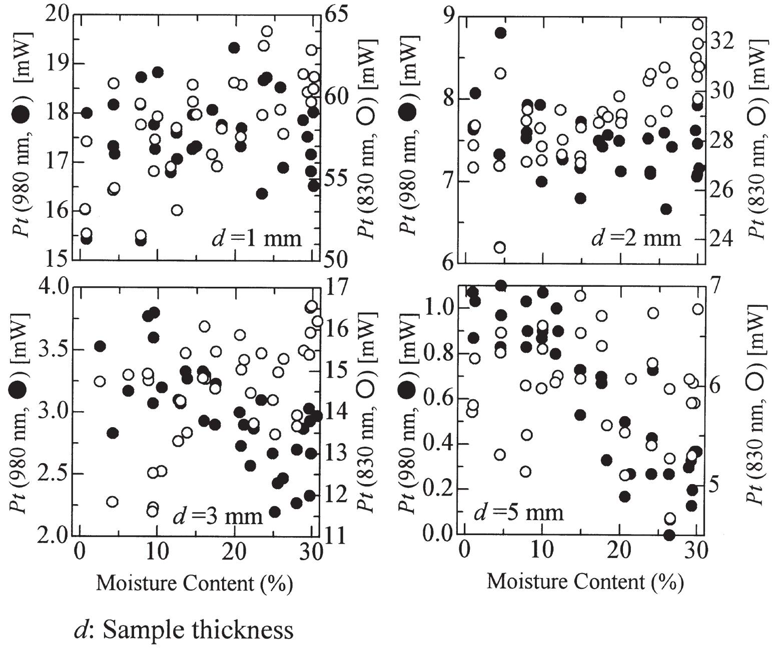


**Figure 2. Relationships between transmitted output power *Pt* and moisture content.**

absorption of the water. Then, the behaviour of *Pt* reflects the variation of the optophysical property of wood sample with water adsorption. Such correlation suggests that the adsorption of the water to the wood substance brings about the lowering of reflection and scattering of the near infrared light in the sample. However, the water absorbs a little light at this wavelength. When the substantial amount of moisture in the sample increases, this effect can not be disregarded as the sample thickness increases.

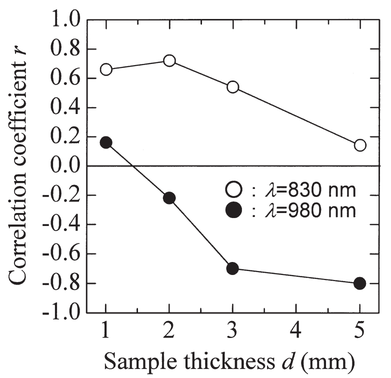


**Figure 3. Correlation between moisture content and transmitted output power *Pt*.**

The increase of the adsorptive water brings about the increase in a transmitted output power from the standpoint of optophysical property. On the other hand, such a phenomenon is connected with the decrease in *Pt* from that of spectrochemical properties. Therefore, the correlation between moisture content and transmitted output power for $d = 5$ mm seemed to be lower, since the effects of both factors on *Pt* may be cancelled.

#### *In the case of λ = 980 nm*

In the case of λ = 980 nm, the negative correlation between *Pt* and moisture content rises as the sample thickness increases. This wavelength is the absorption band of the water, so that *Pt* decreases as the moisture content increases. There-

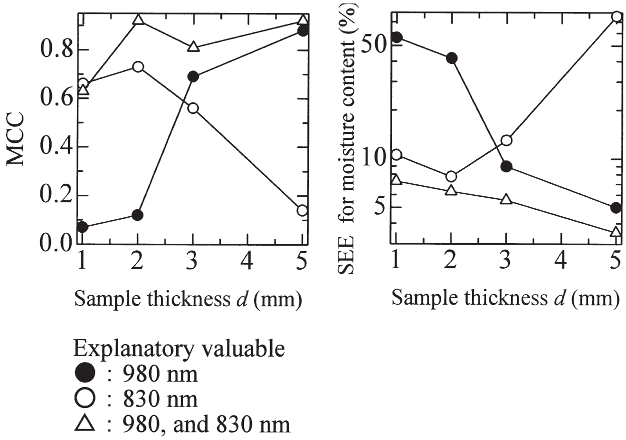


**Figure 4. Variation of *MCC* and *SEE* with sample thickness.**

fore, the relationship between moisture content and *Pt* has a negative correlation. Such a trend is noticeable in the case of $d = 3$ mm or 5 mm, whereas the correlation is very low for $d = 1$ mm or 2 mm. So, we can not simply consider that *Pt* for $\lambda = 980$ nm decreases as the moisture content increases. It is necessary to consider the lowering effect of reflection and scattering of the near infrared light by adsorption of water as well as in the case of $\lambda = 830$ nm When the sample thickness is large where a lot of water is contained, near infrared lights are absorbed successively to reduce the transmitted output power. However, in the case of thin wood samples containing little water, the effect of adsorptive water on the lowering of light reflection and scattering becomes more predominant, so that the correlation between the moisture content and *Pt* lowers.

For the evaluation of moisture content by using such a measuring system, it is important to understand the effect of adsorptive water on the variation of optophysical and spectrochemical properties of wood correctly.

## Calibration equation for moisture content

Here, the calibration equations for moisture content, on the basis of the experimental values mentioned above, were examined. For the first step, we tried to find the simplest calibration equation having one explanatory value on the transmitted output power *Pt*. Furthermore, a multiple regression analysis was examined. Figure 4 shows the variation of multiple correlation coefficient *MCC*) and standard error of estimate (*SEE*) for each statistical analysis with sample thickness.

In the case of $\lambda = 980$ nm, the prediction accuracy increases rapidly as the sample thickness increases. On the other hand, the prediction accuracy at $\lambda = 830$ nm decreases as the sample thickness increases. The calibration equation by a multiple regression analysis shows high *MCC* and low *SEE*, which might be affected little by the sample thickness.

## Effect of free water on transmitted output power

It is important for the wood industry to determine the presence of free water, especially for the drying process of green wood. Here, the variation of transmitted output power with the presence of free water was examined. The samples of Sitka spruce in fully saturated water condition were prepared. Then, the sample was dried indoors (23°C and 45% RH) and Pt was measured at the required interval.

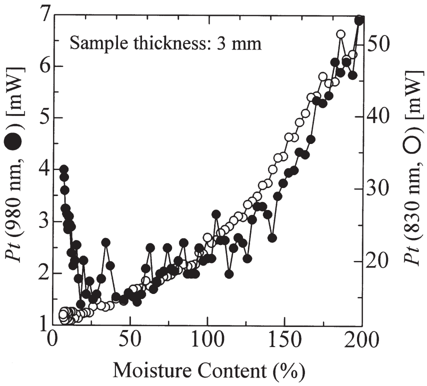


**Figure 5. Variation of transmitted output power *Pt* at wood sample containing free water.**

Figure 5 shows the relationships between moisture content, *MC* and *Pt*. In this figure, white and black circles indicate *Pt* at $\lambda$ = 830 nm and 980 nm, respectively. *Pt* for the wood sample containing free water (*MC* > 30%) increased with each increment of *MC* independently of wavelength. The wood sample has a porous structure, so that the near infrared light is easily reflected or scattered on each cell wall in the air dried condition. On the other hand, the filling of free water in the lumens of tracheids may change the circumstances to retard these light dissipations. In the case of $\lambda$ = 980 nm, however, the variation of *Pt* with *MC* ranging from 30% to 150% is unstable. This may be related to the heterogeneous moisture distribution of the sample surface.

Where *MC* was not more than fibre saturation point or without free water, the relationship between *Pt* and *MC* varied characteristically with the wavelength. These trends for each wavelength correspond to Figure 2. When we consider the variation of *Pt* with the moisture content, it is important to distinguish between the effect of optophysical conditions and that of spectrochemical conditions on them.

## Conclusion

We tried to construct a practical, non-destructive measurement system with a semiconductor near infrared laser with which information on thicker wood samples could be obtained. A series of experiments were carried out which concentrated on monitoring the moisture content of the samples.

Where the moisture content was not more than fibre saturation point, the relationship between the transmitted output power through wood sample, *Pt* and the moisture content varied with the wavelength and the sample thickness. The calibration equation by multiple regression analysis, in which the criterion valuables were *Pt* at $\lambda$ = 830 nm and 980 nm, could perform sufficiently in predicting the moisture conditions independently of the sample thickness. *Pt* for the wood sample containing free water increased with each increment of moisture content independently of the wavelength. The wood sample has a porous structure, so that the near infrared light is easily reflected or scattered at each cell wall in the air-dried condition. On the other hand, free water filling the lumens of tracheids may change the circumstances to retard these light dissipations. When we consider the variation of *Pt* with the moisture content, it is important to distinguish between the effects of optophysical condition and that of the spectrochemical condition on the samples.

Thus, the usefulness of the NIR laser system as a nondestructive measurement of wood was proved by a series of experiments.

## Acknowledgment

This study was supported in part by a Grant-in-Aid for Scientific Research (No. 06454093) from the Ministry of Education of Japan.

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