INVESTIGATION OF OPTICAL PROPERTIES OF BIOLOGICAL TISSUES

Elena Prokopyeva

Doctoral Degree Programme (3), FEEC BUT

E-mail: xproko24@stud.feec.vutbr.cz

Supervised by: Pavel Tománek

E-mail: tomanek@feec.vutbr.cz

Abstract: Optical methods of biological tissue investigation are the most promising in various applications such as biomedicine, agriculture, food control, due to their significant advantages. This paper describes the optical system for measuring optical parameters of back-scattered light, experiments were provided with pork chop slices.

Keywords: biological tissue, scattering, meat ageing, optical properties, polarization

1. INTRODUCTION

The study of biological tissue is a rapidly expanding field of a great interest to those involved into the development of optical medical technologies and food control. Chemical sensors and biosensors, including semiconductor, acoustic and optical devices offer considerable potential for the food composition monitoring and the prediction of its degradation. [1] Compositional analysis with infrared, microwave and ultrasonic techniques offers the advantage of non-invasive hygienic in-line monitoring. These techniques, based on the knowledge of dielectric and acoustic properties of tissues, can be applied to a range of in-line analysis tasks. [2]

Optical methods have a great potential for many applications in biomedicine and agricultural industry, because they are fast, non-destructive, non-toxic and inexpensive. In addition, the optical apparatus is portable and economical [1]. Optical methods for real-time inspection of food and agricultural products can present solutions of problems with speed, accuracy and consistency that are related to inspection of product quality and safety based on its physical and chemical characteristics.

Biological tissue, particularly meat, which is a post-mortem material, is considered to be a random inhomogeneous, anisotropic, chiral medium. Imaging of biological tissue is difficult due to the random multiple scattering of light. Most of biological tissues are non-transparent or highly dispersive. In many current studies biological tissues are considered to be isotropic, i.e. the process of scattering does not depend on the direction of incident light. Nevertheless, there are many tissues such as skin, dentin, skeletal muscles or the white matter in brain that are optically anisotropic [2, 3].

Light scattering in biological tissue originates from its inhomogeneities such as cellular organelles, extracellular matrix, blood vessels, etc. Inhomogeneities in media cause scattering which may change the direction of propagation, polarization and phase of light. Unique angular, polarization and spectroscopic features of scattered light emerging from the tissue, and therefore the information about tissue macroscopic and microscopic structure can be obtained from the polarization characteristics of scattered light [3].

It is important to understand the impact of anisotropic tissue structures on the optical scattering. This knowledge will help in design, development and use of optical methods to obtain accurate information from anisotropic tissues.

2. THE INTERACTION OF LIGHT WITH MATTER

Light is used to measure many parameters, the area of its usage includes various applications in science, technology, biomedicine, agriculture and others. The equipment used for measuring and processing is called optical sensors. Optical sensing is generally noncontact and non-invasive, it provides a very accurate measurement. In these devices optical wave operates as a carrier of information. We can modulate and measure each of the following wave properties and thus characterize the material under investigation – the biological tissue:

- amplitude or intensity,
- phase,
- polarization,
- frequency,
- direction of propagation.

A detected magnitude is always the intensity, because quadratic optical detectors cannot measure optical frequency. A measured property changes the characteristics of wave, and after demodulation it results in the change of intensity. This change of intensity corresponds to the measured property. In some measurements the intensity is modulated directly and there is no need to demodulate before the detection.

When the light falls on the interface between two media, it can be reflected from the surface or it can be refracted from one media to the other. The light can be further transmitted, absorbed or scattered by the material (or a combination of all above mentioned is possible).

The interaction of light with matter can be described by the following phenomena:

- reflection (Fresnel's law),
- refraction (Snell's law),
- transmission,
- absorption,
- scattering, diffusion,
- phase shift,
- radiation,
- polarization.

Different types of interaction are shown on Figure 1.

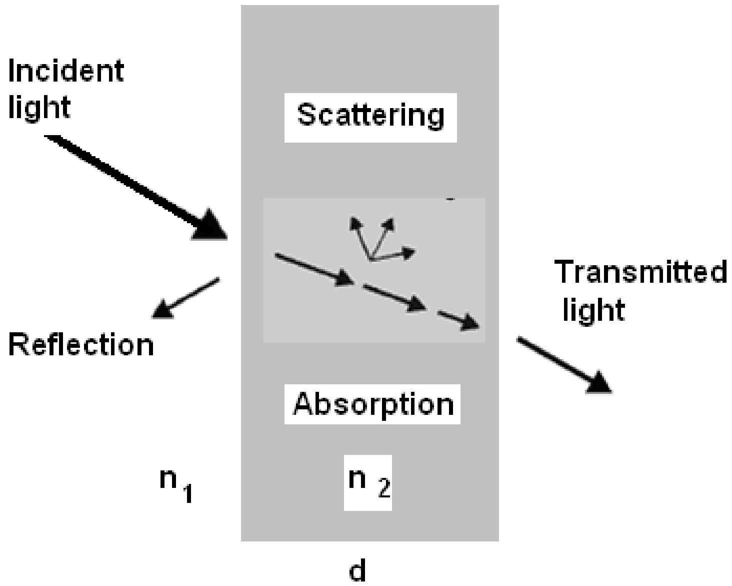


Figure 1: Different types of interaction between light and matter.

State of polarization and intensity of a light beam incident on the medium is specified by the 4×1 Stokes vector **S** in the following form:

$$\boldsymbol{S} = \begin{bmatrix} I \\ Q \\ U \\ V \end{bmatrix} = \begin{bmatrix} S_0 \\ S_1 \\ S_2 \\ S_3 \end{bmatrix}, \quad (1)$$

where $I \equiv S_0$ is total intensity, $Q \equiv S_1$ is polarization at 0° or 90° to the scattering plane, $U \equiv S_2$ is polarization at ±45° to the scattering plane, and $V \equiv S_3$ is left or right circular polarization, and S_0, S_1, S_2, S_3 represent four elements of Stokes vector **S.**

The next magnitude of polarized light radiation transfer is the degree of light polarization *DOP*. It is defined as

$$DOP = \frac{\sqrt{Q^2+U^2+V^2}}{I} = \frac{\sqrt{S_1^2+S_2^2+S_3^2}}{S_0} = \sqrt{(DOP_L)^2 + (DOP_c)^2}\,, \quad (2)$$

where the degree of *linear* polarization DOP_L is defined as

$$DOP_L = \frac{\sqrt{Q^2+U^2}}{I} = \frac{\sqrt{S_1^2+S_2^2}}{S_0}. \quad (3)$$

The quantity $\sqrt{Q^2+U^2}$ represents the magnitude of linear polarization of the optical field. However, it does not specify the orientation of the electric vector.

The degree of *circular* polarization (DOP_c,) is further defined as

$$DOP_c = \frac{V}{I} = \frac{S_3}{S_0}. \quad (4)$$

3. MEASURING SYSTEM AND SAMPLES

The optical measuring system (Figure 2) consists of a linearly polarized laser diode source (λ = 635 nm, output power 5 mW) which illuminates the meat sample, and an analyzer/photodetector combination to measure the scattered light intensity and the polarization properties of the backscattered light. Collimated linearly polarized light from the red laser diode was focused onto a spot on meat surface localized in the center between two electrodes. Myofibers act as optical fibers passing the light more readily along, rather than across their length. A meat slice was superimposed on the mirror which served to enhance the output signal. Transmitted light passing through the sample was reflected from the mirror on the sample holder, reflected back through the meat and combined with the simply reflected light and light back-scattered inside the sample.

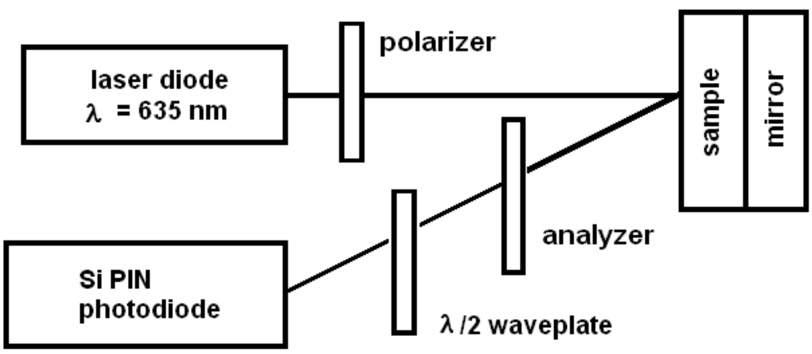


Figure 2: Experimental setup for polarization measurement of backscattered light.

Then the signal was passing through the analyzer (a quarter-wave plate) attached to a rotating mount. It allows to rotate the polarization plane in the range from 0 to 360°. To compensate the polarization plane rotation a half-wave plate was used, that compensates optical activity of the meat sample. Hydrocarbons in muscles have chiral carbon atoms, so the structure is optically active. Back-scattered light was focused on a photomultiplier (with a surface of 25.0 mm^2), minimums and maximums of its polarization intensity were measured.

In order to avoid the detector and analyzer shading, they were placed on the axis at the angle of <15° relative to the optical axis and at a distance of 100 mm from the sample surface.

Pork chop was used as a sample for this investigation, it was cut into slices of 5-10 mm thick. Muscles excised 1 hour after slaughtering were vacuum packed and stored for 24 hours in water at t = 15°C for a slow temperature decrease in order to avoid cold shortening. Hence the measurements started 24 hours later and they were performed 5 times within 3 days period (with interval of 12 hours). Room temperature was 20-23°C during all 3 day period.

4. RESULTS AND DISCUSSION

Figure 3 represents the results of the depolarization measurement depending on the ageing of the pork sample. The thickness of the slice was 1 cm, the temperature in the room ranged between 20 °C - 23 °C during 72 hours. Two curves correspond to linear and circular degree of polarization. It is noticeable that with time the degradation of curves happens, back-scattered light becomes less polarized.

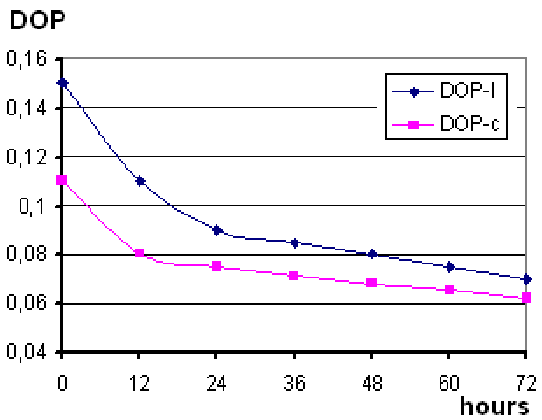
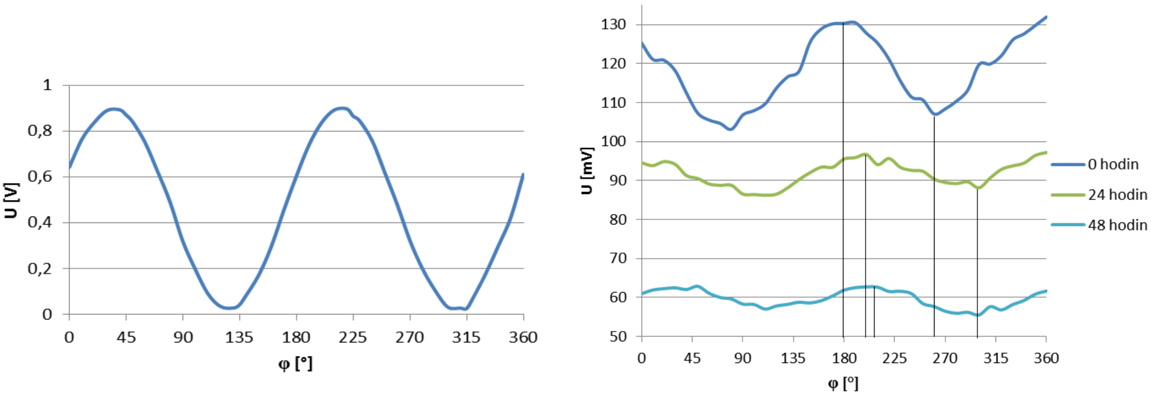


Figure 3: DOP dependence on meat ageing (back-scattered light); sample thickness *l* = 1 cm.

The next experiment was provided with pork chop slices with the thickness 5 mm, at room temperature during 2 days.

Before the measurement with a biological sample, it is necessary to perform a reference measurement in order to see whether the optical system is optimally set. The measurement consisted in the analyzer rotation with the step of 10° within the range of 0° - 360°. The value of the light intensity falling on the photodetector was registered (Figure 4,a). The curve corresponds to a linear polarization. Firstly, we measured a scale when the maximum was set at a polarizer. In the following two measurements we set on the polarizer the value of the maximums +45° and -45°.

Figure 4,b shows how polarizing and scattering properties of the sample change with the influence of degradation. At the beginning of the measurement linear polarization is dominant when light is passing through the sample. At this stage of measurement a biological sample contains large amount of water, this leads to a large scattering of light.



a) b)

Figure 4: Measurement of meat ageing.

It is obvious from the following curves that the linear polarization is gradually changing to circular. At this stage a sample begins to dry out and it does not lead to such strong light scattering as it was in the beginning. Moreover, the gradual degradation of the sample leads to a decreasing of energy values. It is also noticeable that there is a significant shift of minimums (about 30°) and maximums (about 20°) from 0°. It can happen due to the change of refraction index of ageing meat and relatively rapid loss of water from it.

It is possible to say that optical measurement of tissues is very promising in spite of some factors necessary to respect. During the measurement one has to pay attention on such factors as the influence of lightning, stable position of a sample, the results can also be dependent on the sample thickness. Measurements can be complicated by the loss of polarization signal due to the random multiple scattering of light in tissue. It is also important that it is impossible to perform a statistical results processing on the same sample due to the structural changes of it with time. On the other hand it is possible to say that this method does not affect on the sample ageing.

5. CONCLUSION

This work presents the way of assessing meat ageing states by means of a simple apparatus based on the measurement of optical backscattering parameters.

The results show that optical measurements have high potential to be used in the quality control of biological tissues, although they have some limitations and difficulties. However, further research is still needed to restrict effects of the various factors such as pH, state of membranes, fat content and state of maturation.

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