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A FIBEL-OPTIC MODULE FOR BROADBAND SCATTERING MEASUREMENTS WITH ROD LENSES AND CCD PHOTODIODE MATRIX IN THE VISIBLE REGION

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ABSTRACT

A fiber optic module using radially arranged rod lenses for the measurement of broadband scattering was designed. Precise centering of the module was performed. The error deviation and signal interference is reduced to fit in the norms of tolerance. Each rod lens module covers several pixels of the CCD photodiode matrix using an optical fiber. Seven lenses which enter into the structure of the unit register from seven different angles the scattering from the sample. This enables a fast analysis of liquid samples. Fiber optic module with rod lenses can be used for the analysis of scattering spectra of various liquid samples in the food industry. The effect of scattering in different brands of fruit juices was examined. It is shown that the module has been successfully used for the needs of the food industry for analysis of liquid samples. The fiber optic module with rod lenses performs fast test of samples for impurities that get detected by the scattering effects in liquid natural food products.

KEYWORDS: broad spectrum, fiber optic module, rod lenses, scattering.

INTRODUCTION

Currently, researchers in the field of sensor technology focus on improving the construction and the properties of fiber based optical sensors. Fiber optic components can successfully be adapted in combinations with micro-optical components such as lenses, mirrors, prisms, gratings etc.

In the field of sensor technology related to microbiology an increased interest in the simultaneous analysis of several particles is observed. These measurements are carried out with sensors based on simple and effective scheme for the detection of signals using a linear photodiode array CCD.

MATERIALS AND METHODS

Rod lenses for fiber collimators

Rod lenses with a diameter of d = 2. 5 mm a length $L = f_2$ =6 mm, and a focal length f_1 = 4.16 mm have been used. The standard class of these rod lenses is:

- R ≤ 0.4% abs. 400 – 610 nm
- R ≤ 0.3% avg. 400 – 610 nm

One end of the lens is flat, the other is spherically curved. The circumference is polished. Multimode optical fibers of core diameter 200 µm and a numerical aperture NA = 0.22 have been use.

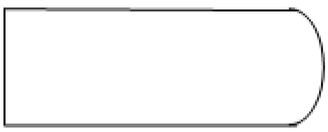

Fig. 1. Rod lens.

Optical fiber rod lens collimator/focuser

Key elements in the construction of fiber optic broad spectrum module are the achromatic rod lenses that focus into or collimate light from optical fibers.

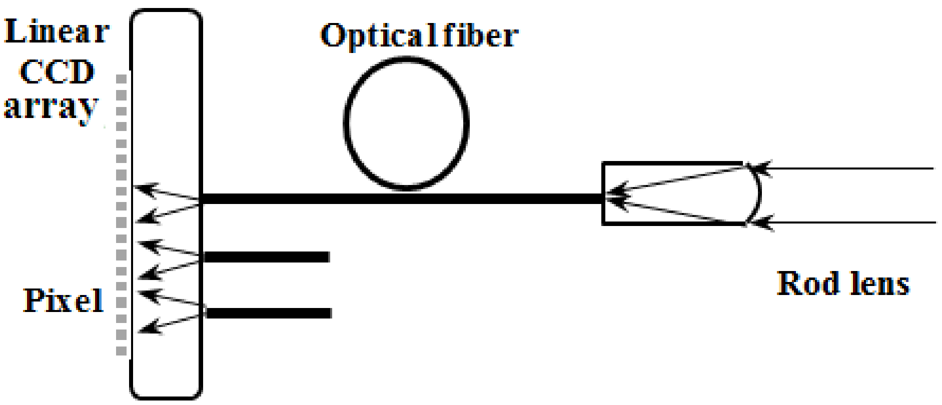

Fig.2. Collimating the light that passes through the rod lens on optical fiber.

The reason why an achromatic rod lens is used is because the focal lengths of the widely used ball lenses and GRIN (grade-index) lenses is wavelength dependent and for scattering measurements white light, or light from LEDs is often used.

Broad spectrum light emitted by the light source passes through the rod lens and reaches the optical fiber, which displays it to the detector.

When light is focused into the fiber by a rod lens, the effective numerical aperture is determined by the rod lens diameter and its focal length f_2 as:

$$NA_{eff} = \frac{d}{2 f_2} \quad (1)$$

which with reference to the rod lens parameters yields $NA_{\text{eff}} \approx 0.2$ for a fiber having an NA = 0.39.

Thus, at the other end of the fiber, the effective numerical aperture will be smaller than the nominal and the bare fiber will illuminate less pixels. This allows to accommodate a larger number of fibers for a total of 128 pixels of the CCD camera. A fiber would illuminate 18 pixels on the average thus light from a total of 7 fibers can be simultaneously analyzed by the unit.

To calculate the radius of the collimated beam we refer to Fig. 3 assuming the fiber tip is on the side of the spherical surface.

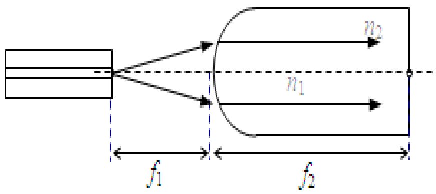

Fig. 3. The basic scheme of a rod lens base fiber collimator.

From the first and the second environment the numerical aperture of the rod lens would be:

$$\mathrm{NA}_1 = \sin\theta_{1,c} = \frac{1}{n_1}\mathrm{NA}_0 \text{ and } NA_2 = \sin\theta_{2,c} = \frac{1}{n_2} NA_0 \quad (2)$$

The height of the ray on the spherical surface will determine the radius of the beam i.e.

$$h_1 = f_1 NA_1 = f_1 \sin\theta_{1,c} = \frac{f_1}{n_1} NA_0 \text{ and } h_2 = f_2 NA_2 = f_2 \sin\theta_{2,c} = \frac{f_2}{n_1} NA_0$$

As $\frac{n_1}{f_1} = \frac{n_2}{f_2}$, it

$$h_1 = f_1 NA_1 = \frac{f_1}{n_1} NA_0 = \frac{f_2}{n_2} NA_0 = f_2 NA_2 = h_2 \qquad (3)$$

For $NA_0 = \theta_0 = 0{,}22$, $f_1 = 4{,}16mm$, $n_1 = 1$,

$n_2 = 1.88577$ it is estimated

$$h_1 = f_1 NA_1 = \frac{f_1}{1} NA_0 = 4{,}16mm \cdot 0{,}22 = 0{,}9152mm$$

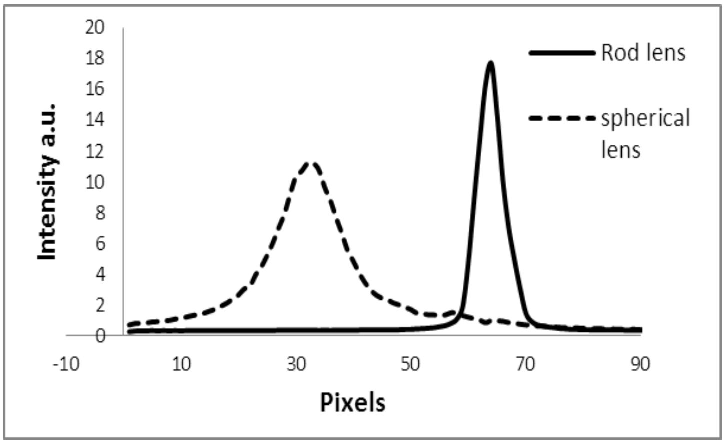

Fig. 4. Distribution of light intensity of a rod lens, broadband source and spherical lens.

If the fiber is at the convex side. We find for h_1 = 0, 9152 mm. The collimated beam of light emitted from the broad spectrum source falls on the rod lens. From there it goes centered in paraxial approximation. So the collimated spot on the fiber end reaches the CCD camera. To show that not in vain has worked with rod lenses. Fig.4 presents mapped distribution of the intensity of the source that have passed through a rod lens and a spherical lens in pixels. It can be seen that the distribution from a spherical lens covers a much larger number of pixels. Unlike the distribution of the spherical lens allocated to rod lens is of the order of 13 pixels, which means that the 128 pixels of the CCD camera can be covered by 8 rod lenses thus covering 8 angles of scattering. If another type of lens is used their number will be less, respectively, thus less angles of scattering will be measured.

The number of pixels that covers a rod lense complies with the number of pixels on the CCD camera. The lenses are uniformly distributed along the detector in order to avoid an overlapping on the distribution of its intensity at scattering angles of the various particles.

Rayleigh scattering

The thermal fluctuations in the fluids lead to random changes in their density, which are described by the rms fluctuation of the density $\overline{\Delta\rho^2}$. Dipole moment $\Rightarrow$ additional dipole moment radiating dipoles, creating an electric field $\Delta E \Rightarrow$ creates I light intensity, which is given by the formula:

$$I(r) = I_{\parallel}(r) + I_{\perp}(r) \qquad (4)$$

where $I_{\parallel}(r)$ и $I_{\perp}(r)$ are the intensities of the the light polarized respectively parallel and transverse to the direction of propagation of the beam, which are given by the following expressions:

$$I_{\perp}(r) = I_0 \frac{1}{2r^2}\left(\frac{2\pi}{\lambda}\right)^4\left(\frac{n^2-1}{n^2+2}\right)^2\left(\frac{d}{2}\right)^6 \text{ and } \quad (5)$$

$$I_{\parallel}(r) = I_0 \frac{\cos^2\theta}{2r^2}\left(\frac{2\pi}{\lambda}\right)^4\left(\frac{n^2-1}{n^2+2}\right)^2\left(\frac{d}{2}\right)^6$$

where I_0 is the intensity in the center of the examined volume V_0, n is the refractive index of the medium, r is the distance from the observer to a particle whose diameter is d, and θ is the angle of scattering.

The sum of the two intensities of the two polarisations leads to:

$$I(r) = I_0 \frac{\cos^2\theta}{2r^2}\left(\frac{2\pi}{\lambda}\right)^4\left(\frac{n^2-1}{n^2+2}\right)^2\left(\frac{d}{2}\right)^6 \qquad (6)$$

Mie Scattering.

Mie dissipation occurs when the particle size *d* is 0,1 λ << d <10 λ. Particles that satisfy the above condition are dust, pollen, smoke, water drops and the like in the lower atmosphere. Mie scattering is the reason clouds appear white.

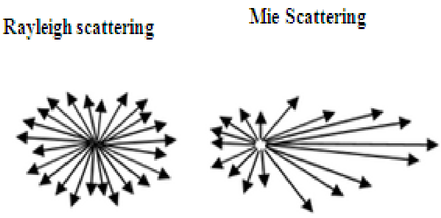

Fig. 5. The difference between the fields of Rayleigh and Mie scattering.

EXPERIMENTAL SETUP

The construction of the broadband fiber optic module with rod lenses was carried out after a precise assembly of its parts. The lenses consist of two parts of different glasses to compensate for chromatic dispersion and ensure the transmission and focusing of broadband (white) light into the fiber. Each of the lenses needed to cover the whole range of pixel photodiode array was installed as described in section 2.1. The lenses were arranged in a common module, with a broad spectrum light source and a quartz cuvette. Light from the source impinging on each lens is lead out via an optical fiber to a photodiode matrix. The detection unit is based on a 128-pixel CCD linear array with an integrated low-noise charge-amplifier featuring high sensitivity, a low dark current and high stability. Two high-speed capacitive-based analog-digital converters (ADCs) transform the analog data from the CCD sensor. The range of each lens is displayed on a computer using specially written software tailored for specific model CCD. Block diagram of the broad spectrum fiber optical module with rod lenses is presented in Fig.6.

Broad spectrum fiber optic module with rod lenses provides a fast and qualitative measurements as in biosensorics for testing different substances and bacteria as well as other organic products. Several independent from each other particles can be tested with a broad spectrum source. This will facilitate research in biophotonic schemes and can reduce costs.

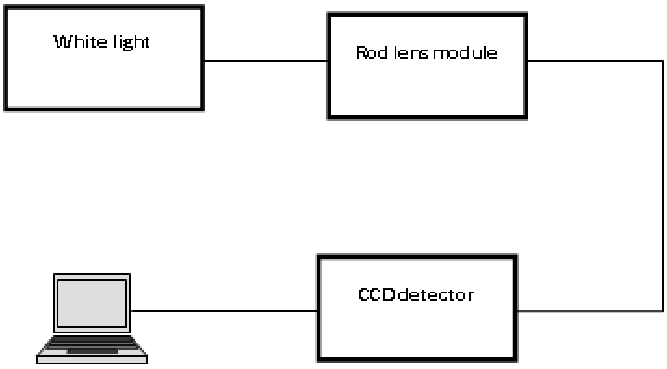

Fig.6. Block diagram of the broadband fiber optical module with rod lenses.

Application of the broadband fiber optic module with rod lenses in the foof industry.

The constructed broad spectrum fiber optic module with rod lenses can be used to determine the scattering spectra of liquid samples. In the construction of the module is included quartz cuvette, where the desired sample is poured and then irradiated with white light.

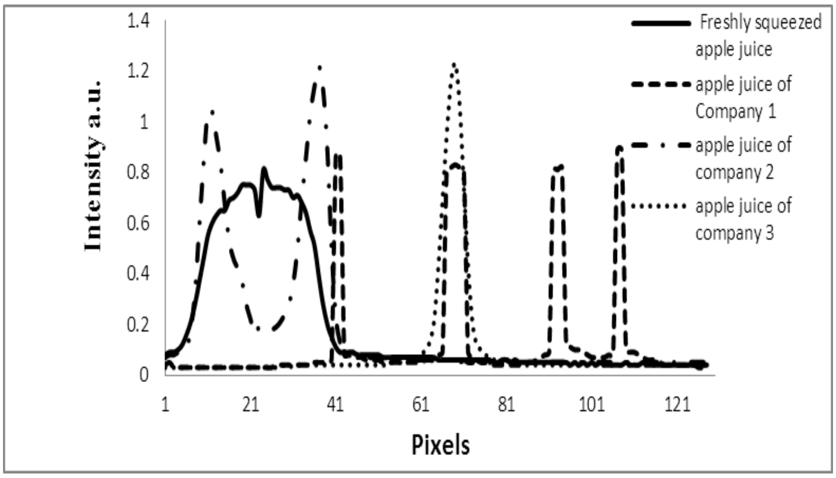

Fig.7. Angular scattering comparison between natural apple juice and apple juice made by two different companies.

Each of rod lens accepts light from various angles of scattering particles included in the composition of the tested sample.

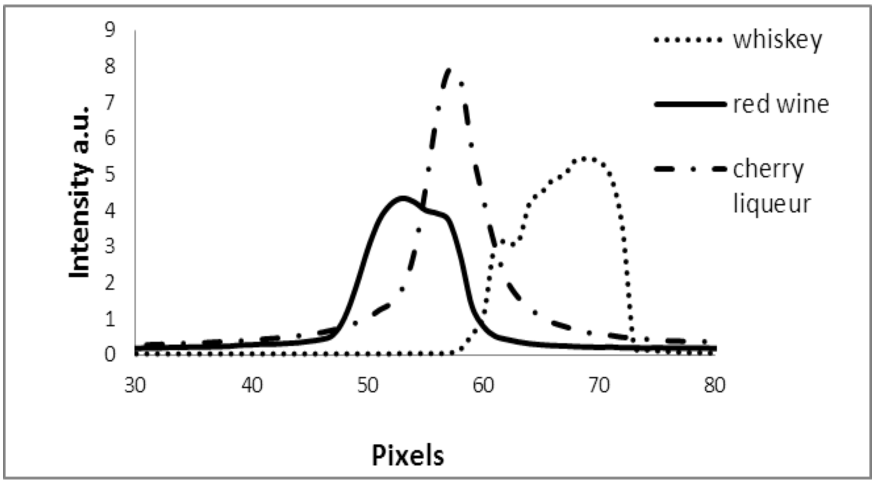

Fig. 8. Angle of scattering from various alcohol drinks.

Fig. 8 shows a difference between the right-scattering spectra of three widely used alcoholic beverages. Watching spectrum of intensive concentrated cherry liqueur and wider and less concentrated scattering spectra of the whiskey and red wine. With the help of a broadband fiber-optic module can be done rapid scattering analysis to characterize the types of alcohol.

In Fig. 9 clearly shows the difference in the angle scattering of yogurts with different fat taken from the same manufacturer. When testing products from the dairy industry is preferred that they be liquid. Not often performed tests already received yogurts.

The ability of the broad fiber-optic module with rod lenses to analyze by the method of scattering fat in yogurts would have decided a lot of problems in the dairy industry. The system can perform tests on ready-made products and market them categorized by fat, which means that it would be quite a boon to the end user. Problem with supply of yogurts with unregulated fat would be solved by this broadband fiber-optic module with rod lenses for this purpose do not even need a rich library as percentage of fat to trivial yogurts are standard.

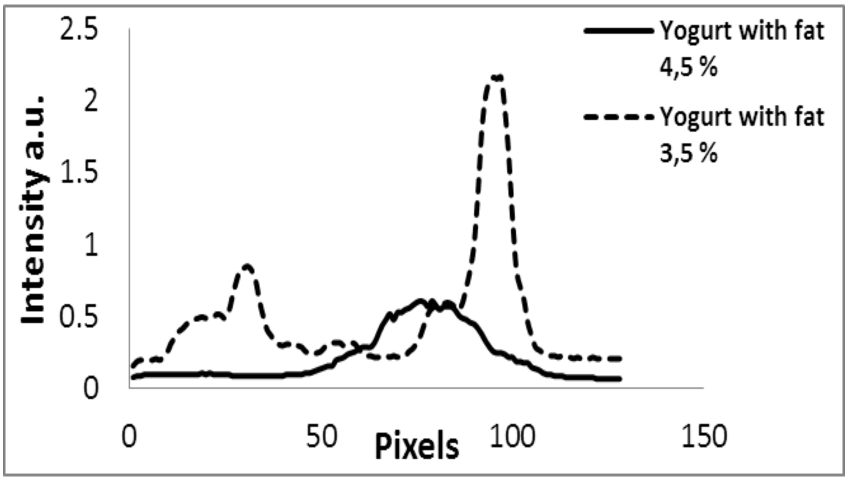

Fig. 9. Angle of scattering from milk with different fat content of the same manufacturer.

CONCLUSIONS

A broad spectrum fiber optic module using rod lenses for the angular measurement of scattering has been proposed. A precise adjustment of the lenses has been performed. Using the module, a number of particles can be analyzed thus saving time for the analysis of liquid samples. The broad spectrum module features a sensitivity to low concentrations of particles which makes it convenient for the analysis of liquid samples for the food, cosmetic, medical and other industries which require a given level of sample purity. The fibers from the broad spectrum module are arranged in one plane and attached to a linear CCD array. And the intensity distributions can be monitored by a suitable software.

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