SPECTROSCOPY AND SPECTRALLY RESOLVED RADIOSCOPY OF BIOLOGICAL SUBSTANCES USING TERAHERTZ FREE ELECTRON LASER RADIATION*

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Abstract

Osteoporosis is a major cause of morbidity of older people. Direct financial expenditure for the treatment of osteoporosis fracture in the U.S. is estimated at $10-$15 billion per year. Though there are a number of methods for diagnostics of osteoporosis, X-ray radioscopy, NMR, element analysis, densitometry, etc., the development of new methods, which are complementary to the existing ones, is highly desirable. We have carried out first experiments on the examination of spectroscopic characteristics of healthy and osteoporosis-affected bone tissues in the terahertz spectral range. The samples were prepared by pressing of grounded bone tissue obtained from the intact rats Wistar and from the senescence-accelerated rats OXYS. The OXYS rats suffered hereditary osteoporosis developed early in life are, therefore, a useful model for examining osteoporosis. The first experiments using a Fourier-spectrometer showed considerable difference in the bone tissue absorbance for two strains, though statistic tests are still required. Because the bone tissue is a highly-absorbing substance, the attenuated total reflection spectroscopy seems to be the most adequate method for detailed bone study. Imaging radioscopy of bone samples using a matrix of microbolometers as a sensor and the Novosibirsk free electron laser as a source of monochromatic terahertz radiation is described.

INTRODUCTION

Osteoporosis is a systemic skeletal disorder characterized by low bone mass and micro architectural deterioration of bone tissue, leading to enhanced bone fragility and an increased tendency to fracture. Osteoporosis has a long latent period and clinically reveals already in the presence of fractures when the bone mineral density is reduced significantly [1]. Thus, for preventing and treatment this disease the early diagnosis is necessary. Today there are several experimental techniques in diagnostic of the osteoporosis such as dual X-ray densitometry and computer tomography, NMR, etc. In spite of high developing and routine of such technique for bone research, the using of terahertz radiation can give complementary information about the bone tissue characteristics that can be valued for diagnostic of osteoporosis.

Recently, the capabilities of terahertz spectroscopy for bones research have been started to investigate. Until now, a few researches of bones using the terahertz time-domain spectroscopy (TDS) have been done. This technique allows obtaining information on the bone density and the complex refractive index. Bone A technique for the computer tomography of bones based on TDS had been demonstrated in the paper [2]. The information about the optical properties of three-dimensional (3D) structures of the investigated bone in the far-infrared region was obtained. Newly developed high-power terahertz sources, such as the Novosibirsk free-electron laser, open up new possibilities for bone radioscopy and imaging, including study of dynamical processes [3].

The goal of this study was the investigation of capabilities of osteoporoses diagnostics by comparison absorption spectra of normal and osteoporosis bone tissue. As a modal for the investigation two genetic strains of rats were chosen, Wistar (intact rats) and OXYS (senescence-accelerated rats with the early onset of osteoporosis). The strain OXYS was founded at the experimental animal laboratory of Novosibirsk Institute of Cytology and Genetics. The animals of this strain have a particularly short life span and accelerated development of age-

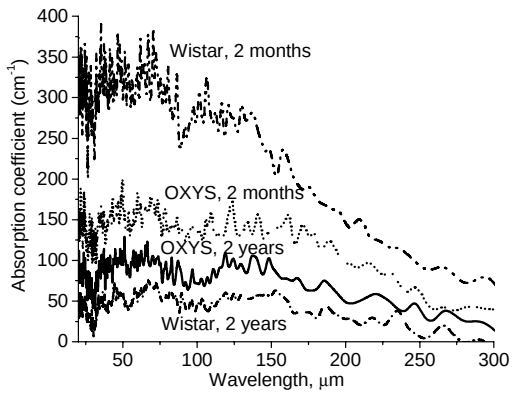

Figure 1: Absorbance vs. wavelength for the bone samples of intact (Wistar) and senescence-accelerated (OXYS) rats of different ages.

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associated pathological phenotypes similar to several geriatric disorders observed in humans.

METHODS AND RESULTS

Fourier-spectrometer measurements

The transmission spectra in the region of 30-300 μm for the bones of two-month and two-year Wistar and OXYS rats were recorded using a Fourier-spectrometer Bruker IFS66v/S (Fig. 1). The samples were prepared by pressing of grounded bone tissue into 200-400 μm thick tablets. Previously, bones from rats were lyophilized and reduced to fragments into the powder in the agathic mortar. The characteristic size of the powder particles was less then wavelength of the THz radiation used in our experiments.

Measurements of the tablet spectra reveal significant absorption of terahertz radiation. So high absorption can be attributed to the absorption of liquid water, which is present in bone tissue in the free and bonded state. The plots in Fig. 1 show clear difference between the extinction coefficients for two-month Wistar and OXYS rats, as well as (may be not so clear) for the two-year animals. Unfortunately the signal magnitude at the Fourier spectrometer detector in these experiments was near the FS noise. To increase the reliability of the measurements we have started study of the extinction coefficient using an attenuated total reflection (ATR) spectroscopy.

Attenuated total reflection technique

ATR is a one of the most adequate techniques for the spectroscopy of highly absorbing substances. The comparison of capabilities of spectrometers for terahertz spectral range is shown in Table 1. Recently, a two-beam ATR spectrometer meant for the operation with tunable FEL was developed [4]. This system was tested using the samples with known optical constants (water, hexane, and benzene) and are showed a good agreement with reference data. Measurements of bone spectra using the ATR spectrometer are in progress.

Table 1: Comparison of capabilities of spectrometers for terahertz spectral range

Capability	Spectrometer type		
	FS	AS	ATR
Measurement of highly absorbing samples	∓	∓	+
Measurement of low absorbing samples	+	+	∓
No impact of reflection	−	−	+
No impact of scattering	−	−	+
Measurement of real and imaging parts of the refraction index	−	−	+
Capability for 2D imaging spectroscopy	−	+	+

Radioscopy with microbolometer matrix

Spectrally resolved terahertz radioscopy of the bones is a prospective technique for the examination of internal bone structure and detection of osteopathy location. We applied a 120×160 pixel microbolometer matrix [5] for the radioscopy of the rat bones. The experimental setup is shown in Fig. 2 and two recorded images are presented in Fig. 3. Intensity distributions along one of the matrix rows are shown in the plot for the initial beam and for the beam passed the bone.

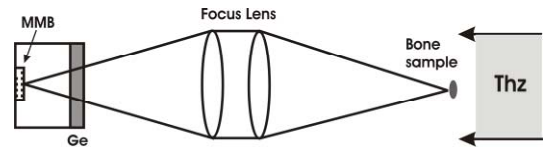

Figure 2: Experimental scheme of radioscopy using MMB with a polyethylene lens.

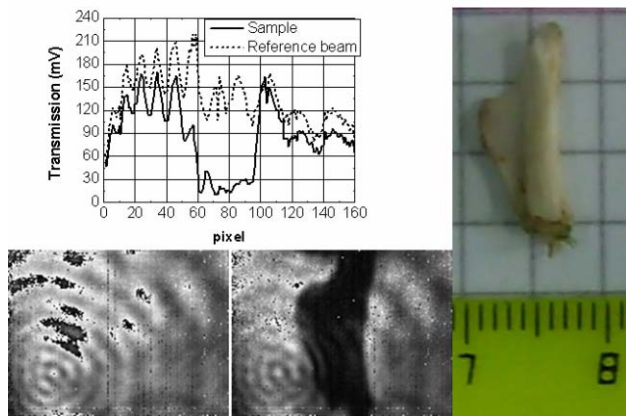

Figure 3: Imaging of rat bones using the MMB: rate 90 frames per second at the bottom (from left to right): reference beam, pass beam through the bone, the bone's photo; at the top: horizontal profile of intensity of the reference beam (dash line) and pass beam (solid line).

CONCLUSION

Thus, the first experiments on rat bone spectroscopy revealed obvious correlation between the absorbance and the strain of two month rats OXYS and Wistar and between of two-year OXYS and Wistar rats. The first radioscopy experiments using MMB showed the capability, in spite of high bone absorption, recording of radioscopic images of bone tissue using terahertz FEL radiation. Further investigations of the bone spectra using ATR technique and radioscopy will give the answer where or not the spectral differences between Wistar and OXYS can be applied for pre-clinical screening analysis of the efficiency of pharmaceutical medicines for osteoporosis treatment.

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