Supercontinuum sources for multimodal MIR-OCT imaging

Ivan Zorin¹, Jakob Kilgus¹, Markus Brandstetter¹, Rong Su³, Bettina Heise^{1,2}

¹ Research Center for Non-destructive Testing (RECENDT), 4040 Linz, Austria

² Johannes Kepler University Linz (JKU), 4040 Linz, Austria

³ Manufacturing Metrology Team, Faculty of Engineering, University of Nottingham, Nottingham NG8 1BB, UK
Ivan.Zorin@recendt.at

Abstract: In this paper we present a multimodal OCT imaging system operating in the NIR and MIR spectral region. NIR/MIR Supercontinuum source based multimodal OCT provides new insights in scattering materials. The system combines the modality of OCT and spectroscopy and enables a structural and specific characterization of different ceramics, polymers or composites. © 2019 The Author(s)
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1. Introduction

Recently the progress in Supercontinuum (SC) source developments has enabled multiple new applications, for example in coherent and non-coherent imaging, in spectroscopy [1, 2] or for data transmission. While at the beginning these SC sources have been covered the near infrared (NIR) range, meanwhile they are advanced also covering the mid infrared (MIR) range. For Optical Coherence Tomography (OCT) imaging these light sources are beneficial due to their low temporal coherence. The higher spatial coherence is rather detrimental for OCT, in particular for full field OCT versions. However, there are also challenges which have to be tackled by the integration into a raster scanning OCT system. In particular noise fluctuations and repetition rates must be adapted regarding the scanning rate of the OCT system which defines finally the usability of different versions of these SC sources. – We will show here a SC based multimodal MIR OCT system applicable in the field of non-destructive testing (NDT).

2. Measurements

Before the operational assemblage of the OCT system the NIR/MIR-SC **source** has been characterized with respect to its noise floor and spectral features. The **relative pulse energy** noise (REN) of the SC source is a key parameter and was characterized for different repetition rates (varied with an external trigger) and power levels. The variance of a sequence of 1000 time-integrated pulses, normalized by the mean value has yielded the relative pulse energy noise level (REN) of the SC source [3]. The REN provides a measure of the wavelength averaged noise. The **pulse forms** were measured using a multiple junction photovoltaic HgCdTe detector (PVM, VIGO) with a time constant of 0.7 ns and then post-processed in Python. The **spectral characterization** of SC has been performed by Fourier transform infrared spectrometer and monochromator measurements.

Figure 1: Scheme of the multimodal MIR Fourier Domain (FD) OCT system

The scheme of the **(FD)-OCT** system is depicted in Figure 1. As a multimodal system it consists of an **OCT imaging modality** and a **spectroscopic modality (SM)**. For the first essential components are: the MIR SC source (based on ZBLAN fiber, 40 mW average power within OCT range), the OCT mirror based grating spectrometer (Czerny-Turner configuration), and the **pyroelectric detector** with synchronized chopper. For the spectroscopic part a microspectrometer (Fabry-Pérot tunable filter, FPTF) can be integrated, for instance enabled by a flippable mirror in the optical path. The optical setting has been **simulated** by ZEMAX, a comprehensive signal processing and **aberration correction** for the wide spectral range have been performed [4].

The FD-OCT system was also characterized and yields a sensitivity (SNR) of about 82 dB, a lateral resolution of 35 μm and an axial resolution around 40 μm . A spatial resolution, and effective probing depth for ceramic samples of up to 1.2 mm was achieved. The frame rate of the acquisition system is currently limited by 100 Hz.

3. Results

First the multimodal MIR OCT system has been exemplified by standard test pattern, like alumina and zirconia plane plates. Later our system was tested for more complicated and composed material systems, like paint and varnish samples for ceramic composites. The layered structures of the ceramic composites could be confirmed by MIR FD-OCT, while a comparable measurement by NIR OCT system failed for recognizing internal details in ceramics specimen, as shown in Figure 2.

Figure 2: (left) 3D OCT volume stack of a composite ceramic structures, measured by MIR FD-OCT; (middle) cross-sectional OCT image measured by commercial NIR FD-OCT system, no internal structures are visible, and (right) the 3D model of the tested ceramic structures. The imaging volume for the 3D MIR OCT stack is 10x10x1.2mm

Furthermore, our advanced MIR FD-OCT also has been demonstrated for imaging in thicker (but weak absorbing) polymer components, e.g. IC cards. Here the hidden, embedded structures, like metallic antennas/electrodes have been visualized through the polymer material, as depicted in the Figure 3.

Figure 3: (left) 3D OCT volume stack of a polymer IC card with integrated chip, measured by MIR FD-OCT; (middle) cross-sectional OCT image measured by commercial NIR FD-OCT system, again no internal structures are visible, and (right) scheme of tested chip card. The imaging volume for the 3D MIR OCT stack is 12x8x1.2 mm

4. Conclusions and Outlook

Summarizing, we have illustrated an elegant multimodal MIR FD-OCT system with pyroelectric line array as detector. We have demonstrated this system successfully for NDT applications of ceramics and polymer composite structures. The SC source enables to discover novel spectral ranges for OCT imaging and probing. We also highlight the spectroscopic imaging features of the multimodal system as well. The OCT system can still be improved by advances in the pyroelectric detector controlling system resulting in an even higher sensitivity for future.

Prospectively, novel applications schemes for characterization of thin artificial teeth components or ceramic coated prosthetics, or for use in art (porcelain) conservation can be envisaged.

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5. References

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