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1310 nm Source Spectral-Domain Optical Coherence Tomography for Chinese Pigment and Jadeite Research

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Abstract

Optical Coherence Tomography (OCT) technique is a nondestructive optical detection technology based on low-coherence interferometer and it has become an attractive cultural heritage research method. A 1310 nm source spectral-domain optical coherence tomography (SD-OCT) system based on optical fiber Michelson interferometer and optical spectrum analyzer is proposed and demonstrated for Chinese cultural heritage research. The cross-section OCT images of Chinese pigment samples and jadeite samples can provide a lot of valuable microstructure information for the Chinese cultural heritage research and identification works.

Keywords

Optical Coherence Tomography, Spectral-Domain OCT, Cultural Heritage

1. Introduction

Optical coherence tomography technology was first proposed in 1991 by D. Huang *et al*. [1], and was used in ophthalmology clinical medical research in 1995. Subsequently, OCT technology got extensive applications in fund of biopsy, oral imaging, dental caries and skin tissues imaging [2]-[4]. In the past ten years, OCT technique researching progress is rapid, its resolution, scanning speed and imaging depth have been greatly improved, and successively developed frequency-domain OCT, Doppler OCT and polarization sensitive OCT. With the growing maturity in medical diagnosis application, researchers expanded the application range of OCT Technology gradually to industrial inspection and artwork research.

From 2004, OCT technology began to be used for surface structure imaging detection of jade [5], ceramic [6] [7] and painting [8]. Especially, researchers obtained many achievements in the study of western painting com-

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pared with the traditional microscopic imaging technology. The varnish and paint layers of western painting can be distinguished easily according to their OCT images of cross sections [9]. The axial resolution of painting's OCT images reached about 10 microns, and the detecting depth was up to 400 microns. OCT imaging has been used to solve the detection problem of under-drawing under the subsurface such as varnishes and glazes due to the ability that OCT can obtain microstructure information [10]. And Liang *et al*. reported the first application of *in situ* OCT imaging on wall paintings combined OCT technology and hyper-spectral imaging technology [11].

In this paper, an SD-OCT system with the central wavelength of 1310 nm is proposed for Chinese cultural heritage research. This SD-OCT system used long wavelength light source and high resolution spectrometer can reach a larger detection depth and display the microstructure information of Chinese pigment samples and jadeite samples clearly. The cross-section OCT images demonstrate that the OCT technology can be used to research the polychrome cultural relics and authenticate authenticity of jadeite products effectively.

2. Experimental Setup and Principle

The schematic diagram of this SD-OCT system is shown in **Figure 1**. This all-fiber OCT system consists of five major components, super luminescent diode (SLD) light source, Michelson interferometer, CCD spectrometer, objective probe with 3× focusing lens and a computer with control circuits. Light emitted from the SLD enters the 2 × 2 20:80 fiber coupler, where it is split into two beams and travel along the reference arm and sample arm respectively. The 2D galvo mirror is used for scanning driver module.

The center wavelength of SLD light source is 1310 nm and the full width half maximum (FWHM) is 60 nm. The resolution of the used spectrometer is 0.06 nm. The theoretical axial resolution (Δz) and imaging depth (z_{max}) of the SD-OCT can be calculated according to the formulas:

$$\Delta z = \frac{2\ln 2}{\pi}\frac{\lambda_0^2}{\Delta\lambda} \tag{1}$$

$$z_{max} = \frac{\lambda_0^2}{4\delta\lambda}\frac{1}{n} \tag{2}$$

where the λ_0, $\Delta\lambda$, $\delta\lambda$ and n are the center wavelength, FWHM of light source, wavelength resolution of spectrometer and refractive index of the sample, respectively. Thus the axial resolution in air is calculated about 12.6 μm and the imaging depth is 7.15 mm. Assuming that the refractive index of jadeite materials is ~1.66, the theoretical imaging depth in jadeite objects is about 4.3 mm. But in practical application, the imaging depth is usually within one millimeter due to the differences of absorption and scattering characteristics of target materials with respect to air and biological tissues. The transparency of the target material can also affect the detection depth of OCT system.

3. Results and Analysis

The SD-OCT system of **Figure 1** was constructed in the laboratory and the drive and control program was written by LabVIEW software. The application of SD-OCT in Chinese cultural heritage research was demonstrated by testing some Chinese pigment samples and jadeite beads.

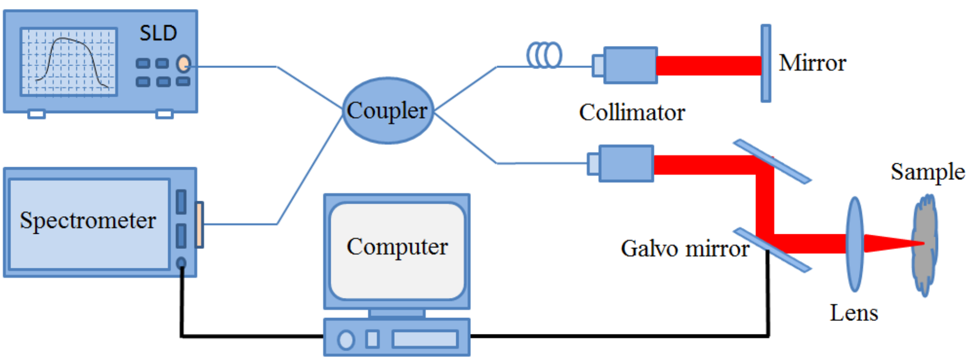
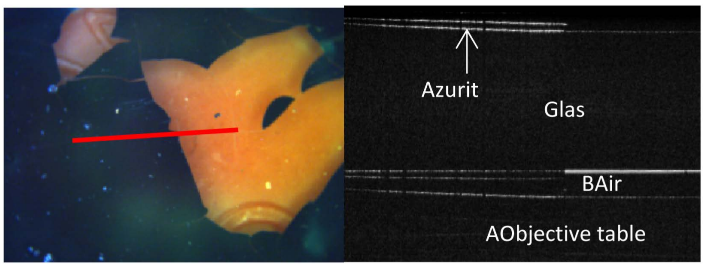


Figure 1. The schematic diagram of SD-OCT system.

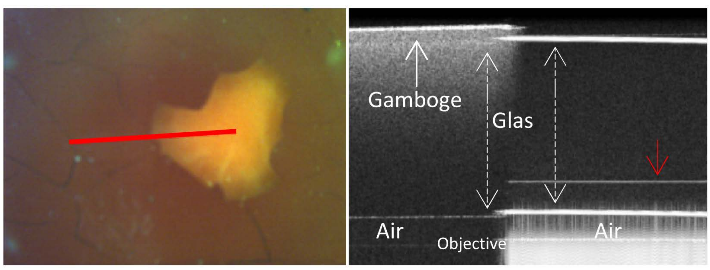
The pigment samples were made by painting the commonly used pigments on the glass slides. After days of natural drying, the pigment layers appeared the phenomenon of cracking, detachment and swell. This is similar to the actual situations of old murals and paintings. These pigment samples can be used to simulate the real cultural relics with pigment layers. After the imaging test of nearly 20 kinds of pigment samples, it was found out that the 1310 nm source SD-OCT system could get clear images of subsurface microstructure of the pigment samples. **Figures 2-4** show the representative azurite, gamboges and ochre samples and their cross-section OCT images (red line position), respectively.

Figure 2(b) shows the cross-section OCT image of the broken location of azurite sample where the pigment layer, transparent glass layer, air layer and nethermost objective table can be distinguished clearly. But the OCT image of gamboge sample in **Figure 3(b)** is different from **Figure 2(b)**. Compared to the clear **Figure 2(b)**, the left and right of **Figure 3(b)** have a slight dislocation in vertical direction. This is the result of OCT image representing only the optical path length rather than the true physical depth. Due to the higher refractive index of gamboge sample, the higher optical path length induces the dislocation in vertical direction. The white line with red arrow mark in **Figure 3(b)** should be the mirror image of the lower surface of glass. The right half ochre sample in **Figure 4(a)** was painted a second layer of ochre pigment and thus the right ochre pigment was thicker than left. The thick pigment layer can be seen clearly in the OCT image in **Figure 4(b)**. From these cross-section OCT images in **Figures 2-4**, we can find out that the OCT technology can be used to research the polychrome cultural relics effectively.



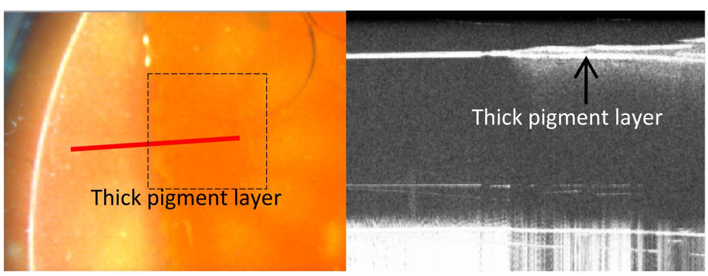
(a) (b)

Figure 2. Azurite sample and its cross-section OCT image.



(a) (b)

Figure 3. Gamboge sample and its cross-section OCT image.



(a) (b)

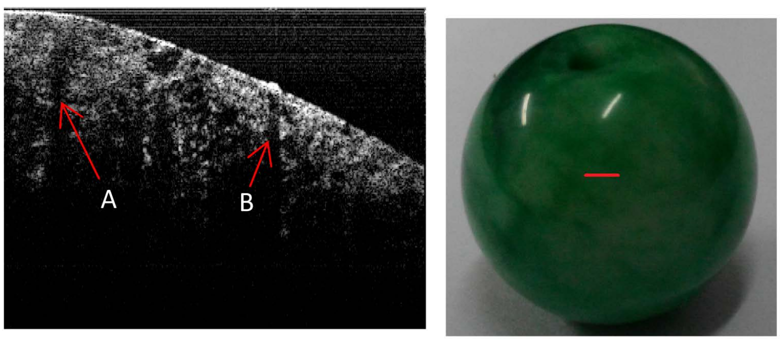
Figure 4. Ochre sample and its cross-section OCT image.

Besides the pigment samples, a real jadeite bead and a fake jadeite bead were selected to be tested via OCT imaging method for comparison and analysis (as shown in **Figure 5** and **Figure 6**). In general, it is hard to distinguish which one is false just depend on observation via human eyes or magnifying glass. The fake jadeite manufactured by the modern technology method used compressed stone powder and glue injection processing is almost convincing. Jadeite is a kind of jade and is known as the "oriental gem" due to its expensive and precious characteristics. China has plenty of ancient jadeite cultural relics, and most of them were beautifully designed and great valuable. Thus the antique collection markets appear a lot of fake jadeites. The authenticity identification of jadeites is increasingly important.

It can be seen that the two cross-section OCT images of the real and fake jadeite beads (red line position) have obvious difference in **Figure 5(b)** and **Figure 6(b)**. The jadeite bead of **Figure 5(a)** is carved by using natural stone material. Its cross-section OCT image in **Figure 5(b)** shows the mineral structure of natural jadeite. The dark stripes in vertical direction (A and B with red arrow mark) are caused by strong absorbing particles, which are some granular impurities embedded in the high scattering jadeite material. Comparing the **Figure 5(b)** and **Figure 6(b)**, the special layered structure of the fake jadeite made of glue injection processing is obvious different with the subsurface microstructure of real jadeite. Consequently, the OCT imaging method can be used for authenticating authenticity of jadeite products.

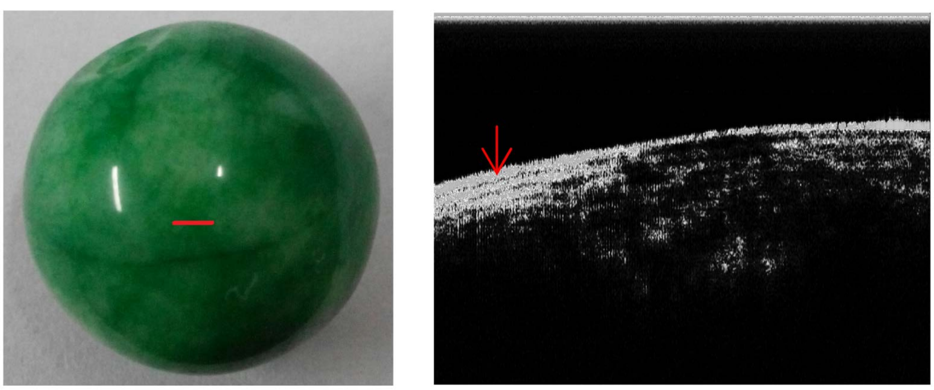
4. Conclusion

A 1310 nm source SD-OCT system and its application research in Chinese cultural heritage are proposed and demonstrated. We got the subsurface microstructure OCT images of the Chinese pigment samples and jadeite bead samples. These high resolution OCT images can display the valuable microstructure information clearly and auxiliary appraisal authenticity. Consequently, the OCT technology can be a good method for Chinese cultural heritage research.



(a) (b)

Figure 5. A real jadeite bead and its cross-section OCT image.



(a) (b)

Figure 6. A fake jadeite bead and its cross-section OCT image.

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