

What is claimed is:

1. Apparatus for measuring the speed of blood in blood vessels in biological samples, in particular, in retinal blood vessels, which apparatus comprises:
 - a source of a beam of radiation having a principal wavelength, which radiation is substantially spatially coherent and has a temporal coherence length which is less than 1 picosecond;
 - means for splitting the beam into a sample beam and reference beam;
 - means for directing the sample beam to an area within the biological sample;
 - means for reflecting the reference beam;
 - detector means for detecting an interference between the sample beam reflected from the area and the reflected reference beam and for generating an interference signal;
 - means for altering an optical path length of the reference beam from the splitting means to the detector means at an effective alteration velocity;
 - analyzer means for analyzing the interference signal to determine the speed of the blood in the area from a frequency spectrum of the interference signal, the effective alteration velocity, and the principal wavelength.
2. The apparatus of claim 1 wherein the analyzer means comprises means for determining a shift of a central frequency of the frequency spectrum of the interference signal from a frequency determined from the effective velocity.
3. The apparatus of claim 1 wherein the analyzer means further comprises means for determining the speed of the blood in the area from the width of the frequency spectrum of the interference signal, the effective alteration velocity, the principal wavelength, and the temporal coherence length.
4. The apparatus of claim 1 wherein the source of radiation is a superluminescent light emitting diode which is focused through a pinhole aperture.
5. The apparatus of claim 1 wherein the source of radiation is a superluminescent light emitting diode which is coupled into a single mode optical fiber.
6. The apparatus of claim 1 wherein the means for reflecting the reference beam comprises at least one reflective surface and the means for altering comprises means for translating the means for reflecting at the effective alteration velocity.

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7. The apparatus of claim 6 which further comprises means for determining the effective alteration velocity and for applying the effective alteration velocity as input to the analyzer means.

8. The apparatus of claim 7 wherein the means for translating outputs a position signal to the means for determining and the means for determining comprises means for differentiating the position signal to determine the effective alteration velocity.

9. The apparatus of claim 6 wherein:
the means for determining the alteration velocity comprises an interferometer means which includes a long coherence radiation source having a principal wavelength, the interferometer means producing an interferometer output signal;

the detection means further comprises means to detect the interferometer output signal and for transmitting the output interferometer signal to the analyzer means, and

the analyzer means further comprising means, in response to the output interferometer signal, for determining the effective alteration velocity from a central frequency of a frequency spectrum of the output interferometer signal and the principal wavelength of the long coherence source.

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10. The apparatus of claim 9 wherein the long coherence length source is a laser.

11. The apparatus of claim 1 wherein the beam is coupled into an optical fiber and the sample beam and reference beams are coupled into optical fibers over at least a portion of their travel paths.

12. The apparatus of claim 11 wherein the means for reflecting comprises means for movement in fixed increments and the means for altering comprises one or more acousto-optic modulators attached to at least one of the reference beam optical fibers.

13. The apparatus of claim 11 wherein the means for reflecting comprises means for movement in fixed increments and the means for altering comprises one or more piezo-electric transducers attached to at least one of the reference beam optical fibers.

14. The apparatus of claim 12 wherein the means for altering further comprises means for translating the means for reflecting.

15. The apparatus of claim 13 wherein the means for altering further comprises means for translating the means for reflecting.

16. Method for measuring the velocity of blood in blood vessels in biological samples, in particular, in retinal blood vessels, which method comprises the steps of:

generating a sample beam having a principal wavelength from a short coherence length Michelson interferometer having a reference beam whose reference beam path is varied at an effective velocity;

aiming the sample beam at a wall of the blood vessel;

scanning the sample beam over the blood vessel in a first direction by varying the reference beam path at the effective velocity and detecting an interference between the reflected sample beam and the reference beam;

determining a first position of a first wall and a first position of a second wall from the interference signal;

determining components of velocity of the blood parallel or antiparallel to the direction of the sample beam from the interference signal by analyzing the frequency spectrum of the interference signal;

scanning the sample beam effectively in a second direction to determine a second position of the second wall;

determining the angle of the first direction with respect to a direction of the blood vessel from the positions; and

determining the absolute velocity from the components of velocity and the angle.

17. Method for measuring the velocity of blood in blood vessels in biological samples, in particular, in retinal blood vessels, which method comprises the steps of:

generating a sample beam having a principal wavelength from a short coherence length Michelson interferometer having a reference beam whose reference beam path is varied at an effective velocity;

aiming the sample beam at a wall of the blood vessel;

scanning the sample beam over the blood vessel in a first direction by varying the reference beam path at the effective velocity and detecting an interference between the reflected sample beam and the reference beam;

determining a first position of a first wall from the interference signal;

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determining components of velocity of the blood parallel or antiparallel to the direction of the sample beam and a first position of a maximum of velocity from the interference signal by analyzing the frequency spectrum of the interference signal;

scanning the sample beam effectively in a second direction to determine a second position of a maximum of velocity;

determining the angle of the first direction with respect to a direction of the blood vessel from the positions; and

determining the absolute velocity from the components of velocity and the angle.

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SHORT COHERENCE LENGTH, DOPPLER VELOCIMETRY SYSTEM

Abstract of the Disclosure

Apparatus for measuring the speed of blood in blood vessels in biological samples, for example, in retinal blood vessels, which apparatus includes: (a) a source of a beam of radiation having a principal wavelength, which radiation is substantially spatially coherent and has a temporal coherence length which is less than 1 picosecond; (b) a beam splitter for splitting the beam into a sample beam and reference beam; (c) optical apparatus for directing the sample beam to an area within the biological sample; (d) a reflector for reflecting the reference beam; (e) a detector for detecting an interference between the sample beam reflected from the area and the reflected reference beam and for generating an interference signal; (f) apparatus for altering an optical path length of the reference beam from the beam splitter to the detector at an alteration velocity; and (g) an analyzer for analyzing the interference signal to determine the speed of the blood in the area from a shift of a central frequency of a frequency spectrum of the interference signal from a frequency determined from the alteration velocity and the principal wavelength.

FIGURE 3