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Compact Dual-Wedge Point-Scanning Confocal Reflectance Microscope

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Abstract

Confocal reflectance microscopy has been shown to provide optical sectioning and resolution sufficient to provide useful information about skin to a depth below the epidermis. However, existing instruments are large and expensive, because of the need for fast two-dimensional scanning in the pupil, and the associated relay optics. A more compact scanning system could lead to an affordable hand-held instrument for in vivo imaging. Several approaches are being considered with different advantages and disadvantages. Here we report one approach that incorporates a dual-wedge scanner within a point-scanning configuration. The dual-wedge scanner is implemented by replacing the two scanning mirrors and the telescope between them with two optical prisms that are rotated about the optical axis. This scanning configuration produces a spiral scan if the prisms are rotated in the same direction, or a rosette scan if the prisms are rotated in opposite directions. Preliminary experimental results with the microscope show a lateral resolution on the order of 1 - 2 µm and on-axis optical sectioning on the order of 3 - 4 µm.

Introduction

- Confocal microscopy performs optical sectioning:
  - A thin section within tissue is imaged non-invasively, with high contrast and three-dimensional resolution on the order of micrometers (Figure 1).
- Several efforts under way to design a hand-held confocal reflectance microscope with comparable image quality to larger devices.
- Dual-wedge (Rotating Prism) scanning is a well-known scanning technique but has had minimal use within an imaging instrument.

State of the Art

- Skin cancer is one of the fastest growing cancers
  - 1.2 million new cases diagnosed every year in the United States.
- Of the 5.5 million biopsies performed every year, 80% turn out to be benign and could have been avoided.
  - Cost US healthcare approximately $2.2 billion
  - Left patients with unnecessary pain, scarring, and mental anguish
- Confocal reflectance microscopes have already shown to be useful in the detection of skin cancer margins, and clinical testing is currently being performed to determine the true potential of cancer detection.
- Present point-scanning confocal microscopes are complex, expensive and difficult to manufacture.
- A dual-wedge scanner may reduce the size of the scanning instrumentation, thereby simplifying the overall device and decreasing the cost.

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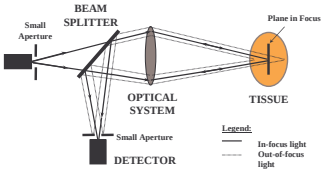


Figure 1 – Confocal Microscopy, "Optical Sectioning"

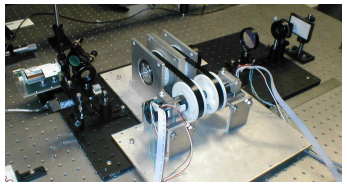


Figure 2 – Dual-Wedge Confocal Microscope

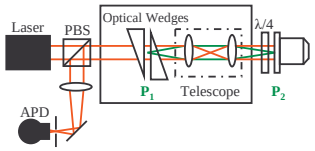


Figure 3 – Optical Layout

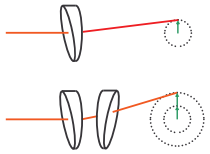


Figure 4a – Prism Deviation

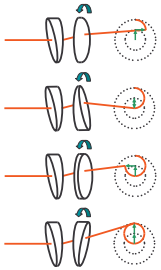


Figure 4b – Scanning Concept

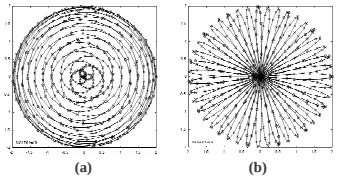


Figure 4c – Scan Patterns for **(a)** co-rotation and **(b)** counter-rotation of the prisms at speeds ω_1 and ω_2.

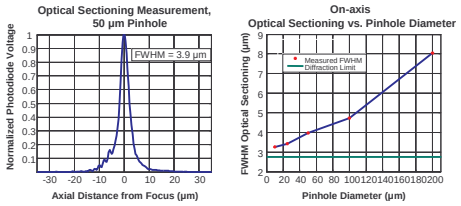


Figure 5 – **(a)** Optical Sectioning measurement; 50 µm pinhole. **(b)** Optical Sectioning measurements for various pinhole diameters.

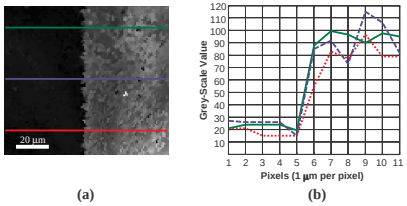


Figure 6 – **(a)** Chrome on glass edge; 100 µm pinhole. **(b)** Plot of intensity values for lines drawn across edge.

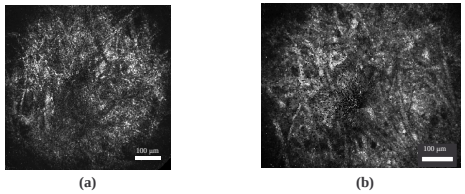
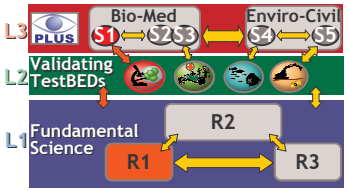


Figure 7 – Paper Fibers with: **(a)** 50 µm pinhole and **(b)** 100 µm pinhole



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Optical Design

- The dual-wedge scanning concept is shown in Figure 4a – 4c:
  - Light passing through a single prism deviates at an angle: $\alpha(n\text{-}1)$, where n is the index of refraction and α is the angle of the prism (Figure 4a).
  - Light passing through two prisms deviates at an angle: $2\alpha(n\text{-}1)$, assuming the prisms are close together (Figure 4a).
  - Rotating the second prism while keeping the first prism fixed scans a circle centered about the point from the deviation of the first prism (Figure 4b).
  - The typical scan pattern developed by rotating one prism at a speed ω_1 and the other in the same direction at a speed ω_2 is shown in Figure 4c(a).
  - The scan pattern in Figure 4c(b) shows the scan pattern for rotating the prisms at speeds ω_1 and ω_2, but in opposite directions.

Results

- On-axis optical sectioning measurements show that the sectioning is 3.2 – 8.0 µm for pinhole diameters of 10 – 200 µm (Figure 5).
- Lateral resolution on the order of 1 – 2 µm has been measured with a 100 µm pinhole (Figure 6).
- Images of paper fibers within a business card with a 50 µm and a 100 µm pinhole show the sectioning ability of the instrument (Figure 7).

Opportunities for Technology Transfer

- This work is in collaboration with Lucid, Inc.
- Lucid, Inc. is the primary manufacturer of confocal reflectance microscopes, called VivaScopes.
  - Current VivaScopes are large, expensive ($70K - $90K), and difficult to use.
- The ideal instrument is hand-held, robust, inexpensive ($20K - $30K) and user-friendly.
  - The $20K - $30K price range allows physicians to have an instrument in every office and will promote educational use.

Conclusions/Future Work

- On-axis resolution (sectioning) of the dual-wedge scanner compares well to that provided by current point-scanning technology.
- The breadboard microscope shows promise for incorporating the dual-wedge scanner within current point-scanning instruments.
- Further work needed to:
  - Optimize the optical design.
  - Decrease the acquisition time.
  - Develop interpolation techniques for irregular scanning pattern.
  - Characterize image quality throughout the field of view.