High-Resolution Microscope Based on Fiber Optic Array, Lenses and Microspheres

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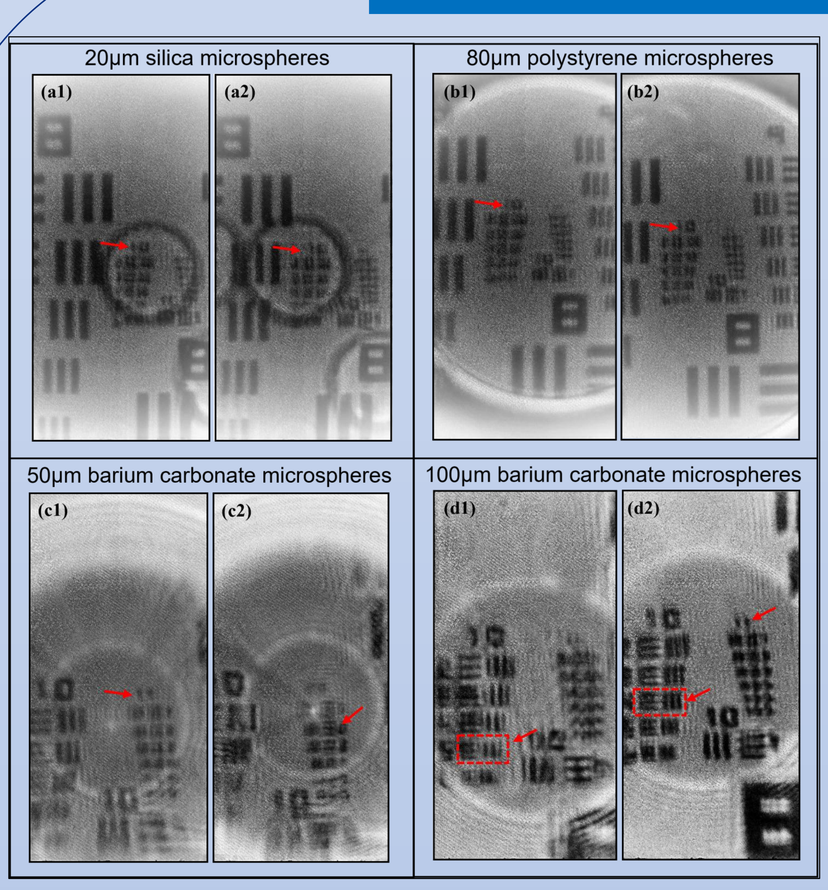
Introduction

In the fast-evolving point-of-care testing (POCT) field, compact microscopes are indispensable, with lens-based components as their optical design core. The team previously verified fiber optic arrays (FOA) can replace traditional lenses, offering distortion-free imaging, high NA, and miniaturization-friendly short working distance. However, FOA-traditional lens microscopes lack resolution for tasks like parasite observation and virus identification.

Given dielectric microspheres enable super-resolution (via evanescent wave conversion and photonic nanojet effect), a new scheme using microspheres, lenses, and FOA as cores is proposed, with performance validated via Resolution-Test-Target (RTT) testing.

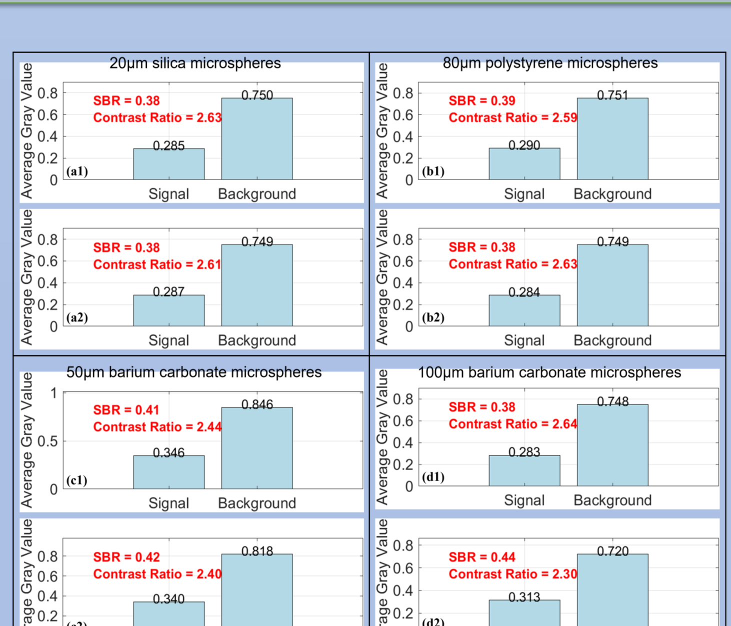
point-of-care testing | fiber optic arrays | high-resolution | microspheres

Results



To study microsphere parameters' impact on system resolution, we tested their materials, diameters and immersion liquids: 100 μm barium carbonate microspheres worked best (305 nm with lens oil), larger/high-NA ones were better.

Fig. 4. System Performance Analysis. (a1) ~(a2) show images captured using 20 μm silica microspheres, (b1) ~(b2) show images captured using 80 μm polystyrene microspheres, (c1) ~ (c2) show images captured using 50 μm barium carbonate microspheres, and (d1) ~(d2) show images captured using 100 μm barium carbonate microspheres. For (a1) ~(d1), special oil-immersion lens oil was used as the immersion liquid, while for (a2) ~(d2), cedarwood oil was used as the immersion liquid.



We also analyzed signal-to-background ratio: same material/diameter, lens oil gave better contrast; 20 μm silica microspheres had best contrast. 100 μm barium carbonate microspheres' contrast trend matched resolution—better with lens oil.

Fig. 5. The signal-to-background ratios (SBR) analysis of each structure in Fig. 4. (a1) ~(a2) corresponds to the SBR of 20 μm silica microspheres, (b1) ~(b2) corresponds to the SBR of 80 μm polystyrene microspheres, (c1) ~ (c2) corresponds to the SBR of 50 μm barium carbonate microspheres, and (d1) ~(d2) corresponds to the SBR of 100 μm barium carbonate microspheres. For (a1) ~(d1), special oil-immersion lens oil was used as the immersion liquid, while for (a2) ~(d2), cedarwood oil was used as the immersion liquid.

Method

The core components of the experimental setup are clearly presented, mainly including an illumination light source (Daheng, GCI-060403), a 100× objective lens (numerical aperture NA = 1.30), a precision stage (model LS90-25C3 from LBTEK), a FOA module (manufactured by China Hongshun with an optical magnification of 6×), and an image acquisition device (Samsung S7 smartphone, equipped with a 12-megapixel camera where the size of a single pixel reaches 1.4 μm).

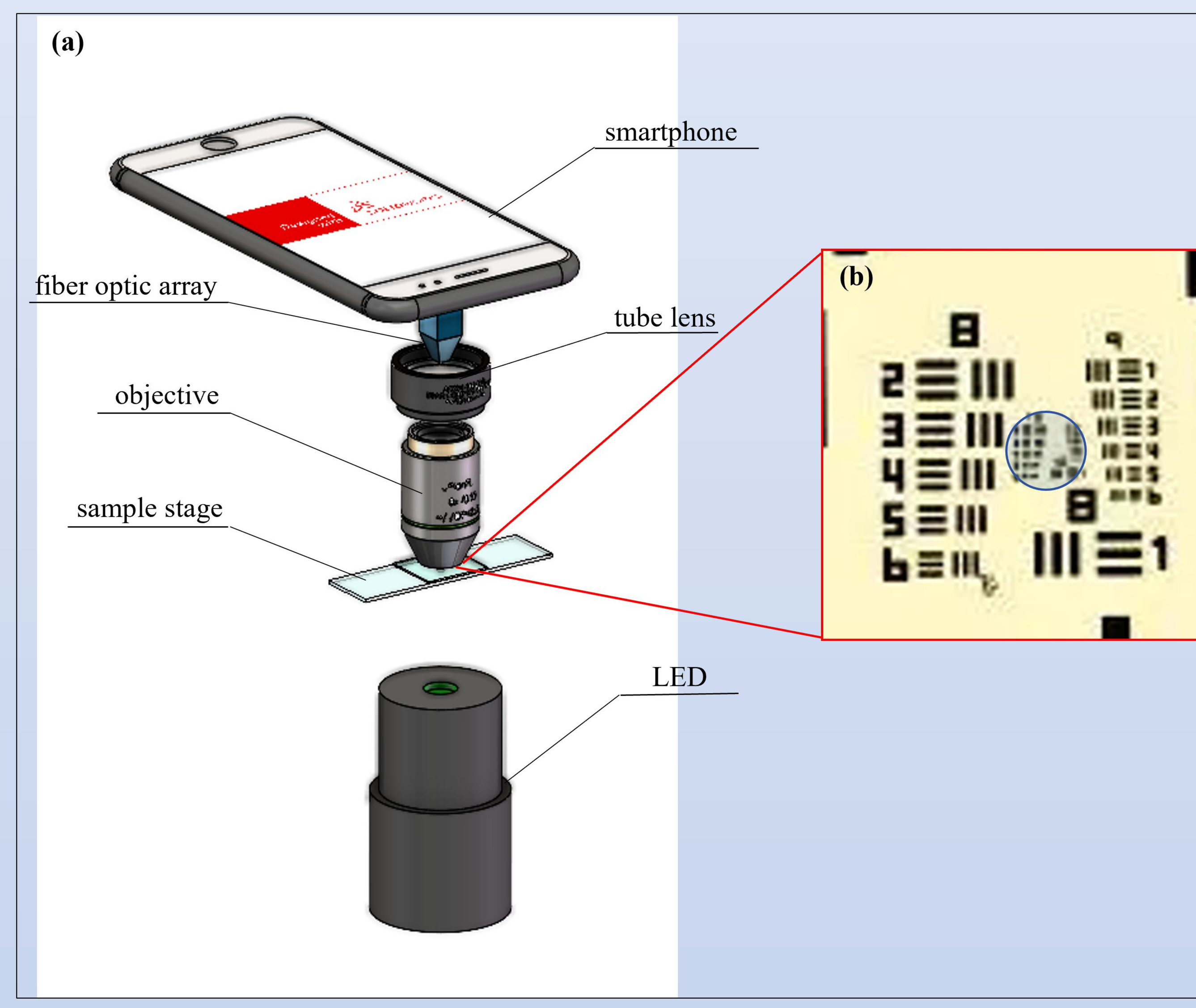


Fig. 1. Experimental setup. (a) Overall optical configuration of the microscope, (b) Resolution target and microspheres: the blue circular regions represent different microspheres.

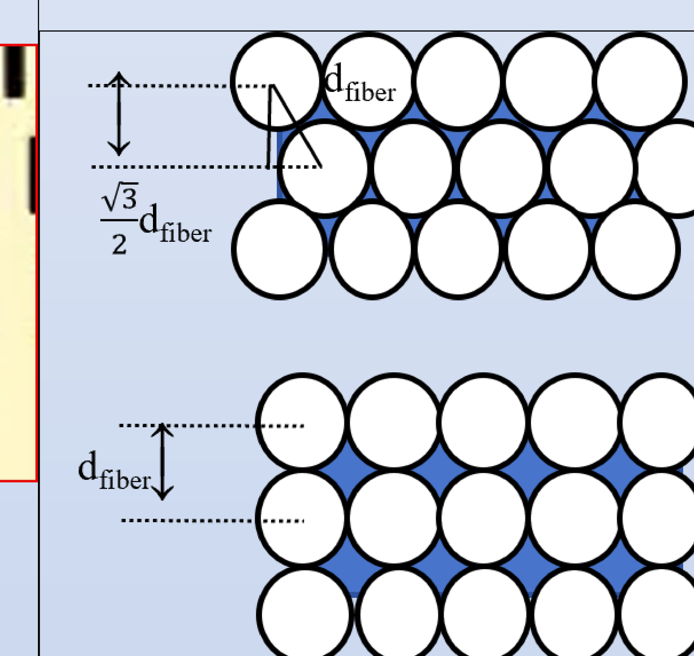


Fig. 2. The quadrilateral and hexagonal arrangement structures of the fiber core at the small end of the fiber optic array.

This diagram illustrates the workflow of a microscopy system. First, an LED light source on the lighting stage transmits light through a sample. Then, in the "Signal collection and primary imaging" stage, microspheres enhance the signal for super-resolution, while a 100× objective lens collects and aligns the light to generate parallel light. Next, during "Relay and secondary imaging", a tube lens forms an intermediate real image, and an FOA passes and shrinks this image. Finally, via coupled transmission, a detection and recording CMOS captures the processed image. The system integrates multiple components to achieve enhanced imaging performance.

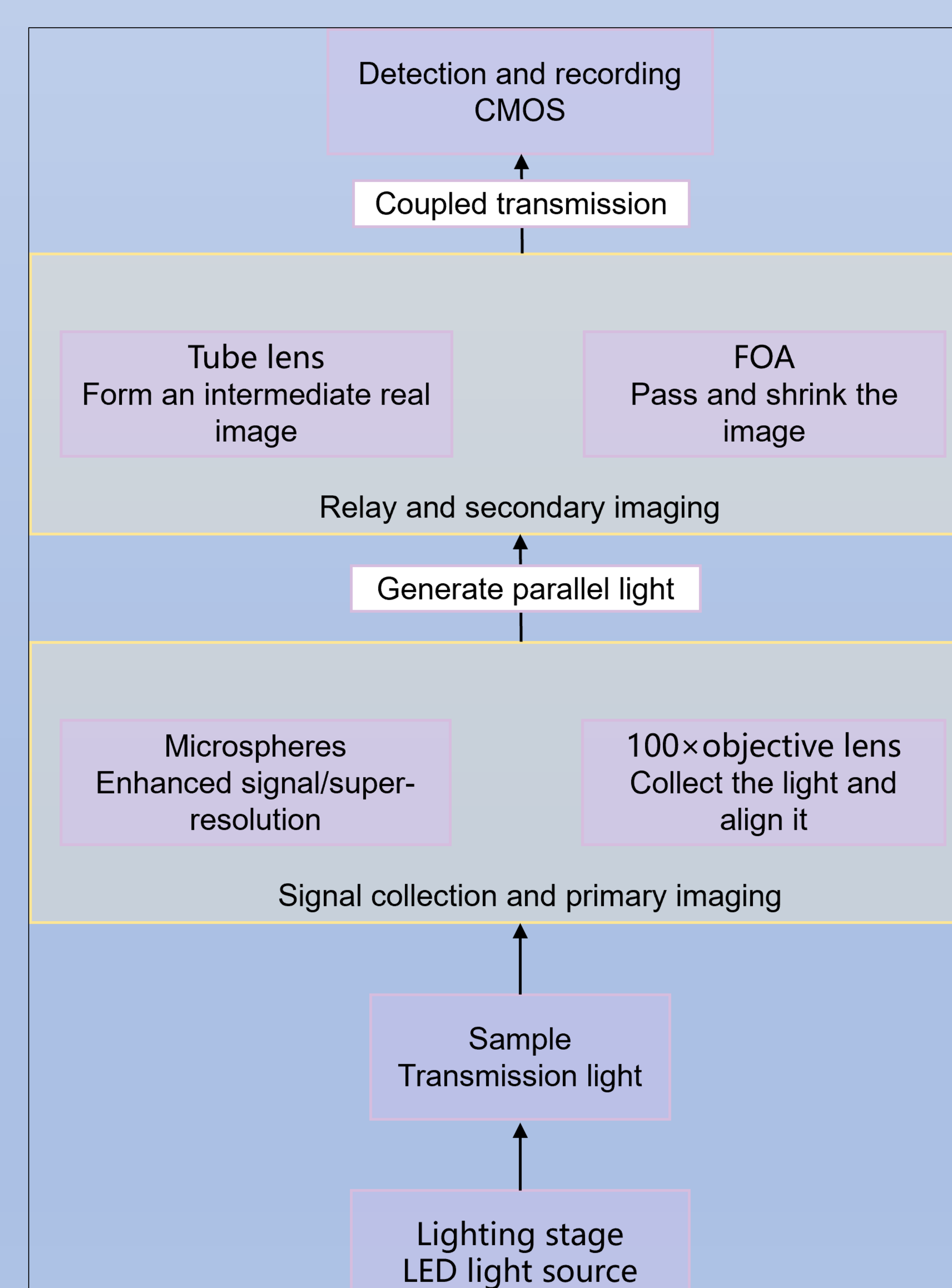


Fig. 3. The workflow of the entire optical path

Conclusion

This study proposes a high-resolution microscopy scheme with microspheres, a tube lens, an objective lens and FOA working synergistically. It breaks traditional FOA's magnification limitations, boosting imaging resolution to 305 nm via microspheres. Comparative tests on microsphere materials, diameters and immersion liquids were done. Optimal resolution is achieved with 100 μm barium carbonate microspheres and lens oil. The compact, stable microscope fits real-time monitoring in resource-constrained scenarios, with potential as an on-site POCT platform.