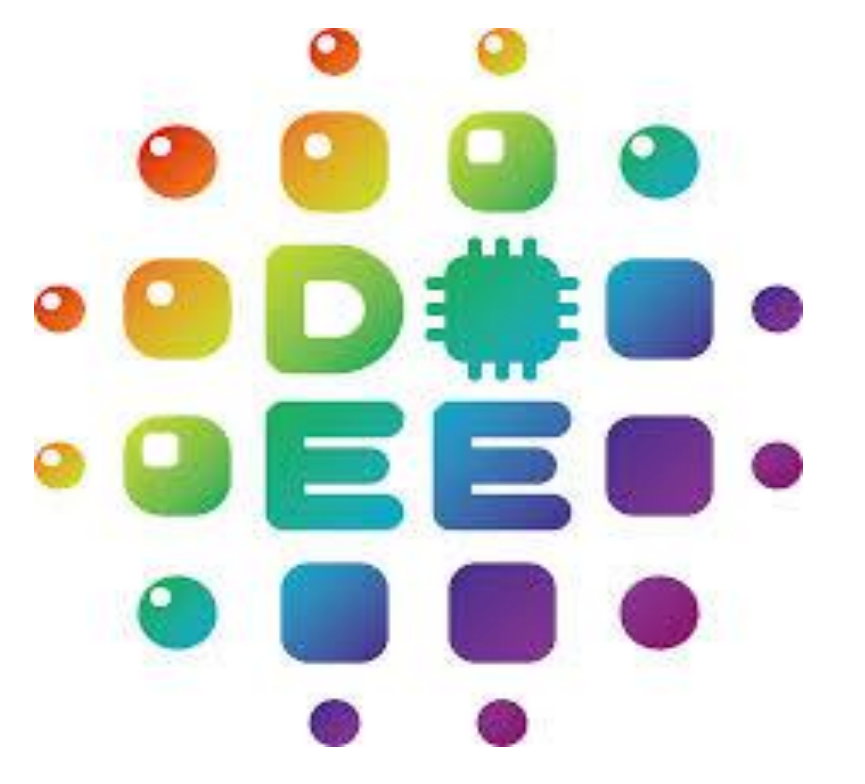




Portable Optical Module Using Integrated μ -LEDs and MEMS Mirrors

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INTRODUCTION

Micro-LEDs (μ -LEDs) are ideal micro light sources owing to their high luminance, long lifetime, and wide modulation bandwidth under high current densities, while their small footprint supports dense and hybrid integration with optical and mechanical structures. Microlens arrays further enhance μ -LEDs emission by collimating and shaping the beam to improve coupling efficiency and uniformity [1]. For dynamic beam steering, μ -LEDs integrate with Micro-Electro-Mechanical Systems (MEMS) mirrors, whose comb-drive or torsional actuators provide fast, wide-angle deflection with CMOS compatibility [2]. Silicon substrates offer mechanical strength, thermal stability, and process compatibility, enabling monolithic integration of μ -LEDs, microlenses, and MEMS mirrors. This compact system achieves miniaturized, power efficient light engines for advanced portable imaging, sensing, and display applications.

Methodology

Traditional optical modules rely on multi-wavelength lasers and MEMS mirrors for beam steering, but their complex alignment and long beam paths lead to bulky packaging and limited portability. As shown in Fig. 1, the proposed compact design replaces lasers with dual-wavelength μ -LEDs monolithically integrated with MEMS mirrors, greatly simplifying the optical layout. The μ -LED array directly generates blue and green emissions, removing the need for wavelength conversion. Silicon reflectors, formed by anisotropic wet etching with 54.7° and 45° facets [3], are bonded to create a sequential optical path guiding μ -LED emission toward the MEMS mirror for dynamic scanning. Integrating etched reflectors, redistribution layer (RDL) routing, and MEMS mirrors yields a compact monolithic structure with reduced alignment effort, lightweight packaging, and CMOS compatibility, presenting a promising platform for portable, highly integrated optical systems.

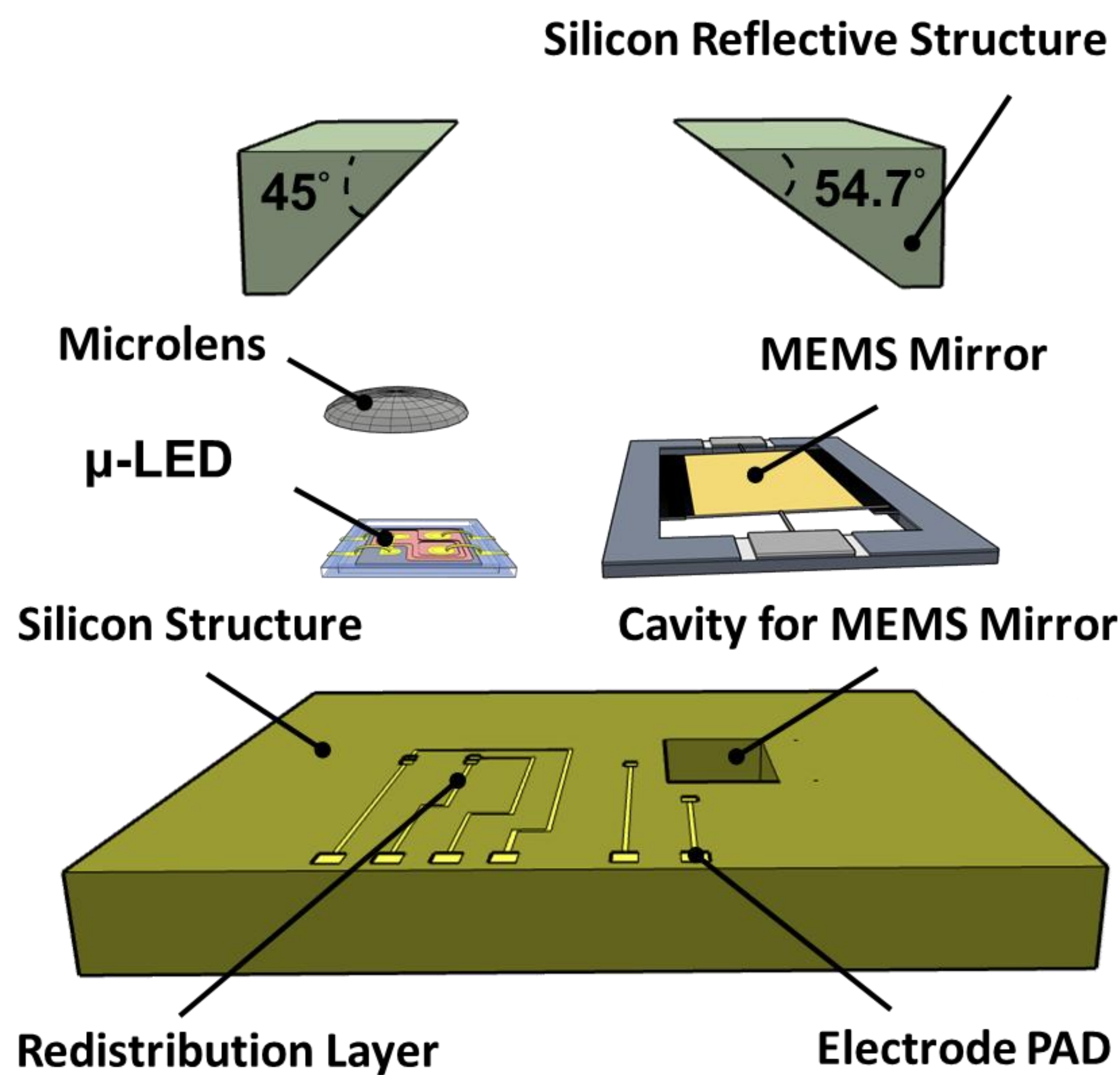


Fig. 1 Structural diagram of portable optical module.

RESULTS

The performance of the dual-wavelength μ -LED emitters is summarized in Fig. 2. Panels (a) and (b) compare the optical and electrical characteristics of the devices: the emission profile shows that the inclusion of a microlens significantly improves beam collimation and intensity uniformity, while the I-V curves indicate turn-on voltages of about 2.0 V for green and 2.5–3.0 V for blue μ -LEDs, confirming stable forward operation. As shown in (c) and (d), the frequency responses under 20 mA and 30 mA driving currents demonstrate enhanced modulation at higher current levels, with distinct peaks observed for both blue and green channels. Each emitter operates independently without electrical or optical crosstalk, validating the stacked dual-wavelength design.

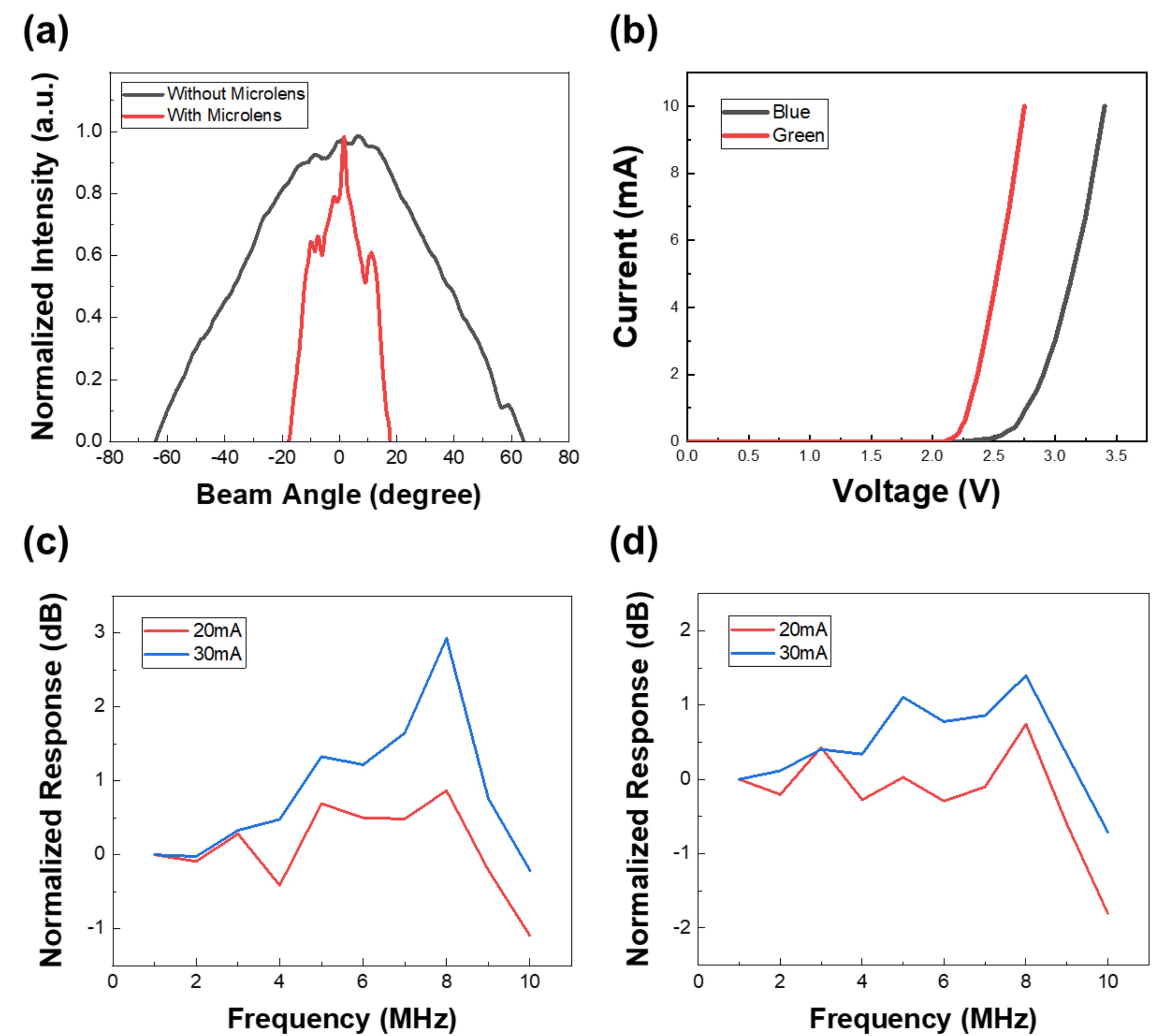


Fig. 2 (a) Beam profile measurement, (b) blue and green I-V curves, (c) frequency response blue emission, (d) green emission of the μ -LED

CONCLUSION

As illustrated in Fig. 3, the experimental setup consists of a current source, optical microscope, photodetector, and analysis system for electrical and optical characterization. The integrated μ -LEDs exhibit stable I-V characteristics, with the blue emitter turning on near 2.5 V and the green near 2.0 V, confirming reliable dual-color operation. Their frequency responses show clear modulation peaks around 8–9 MHz, with the green channel exhibiting slightly higher gain at increased current levels. The inclusion of microlenses improves beam collimation and propagation distance, reducing divergence and enhancing optical coupling efficiency. When paired with MEMS mirrors, the module achieves angular beam steering and flexible light control. This monolithic integration minimizes packaging complexity while maintaining high efficiency, making it well suited for portable visible light communication, compact display modules, and precision optical sensing applications.

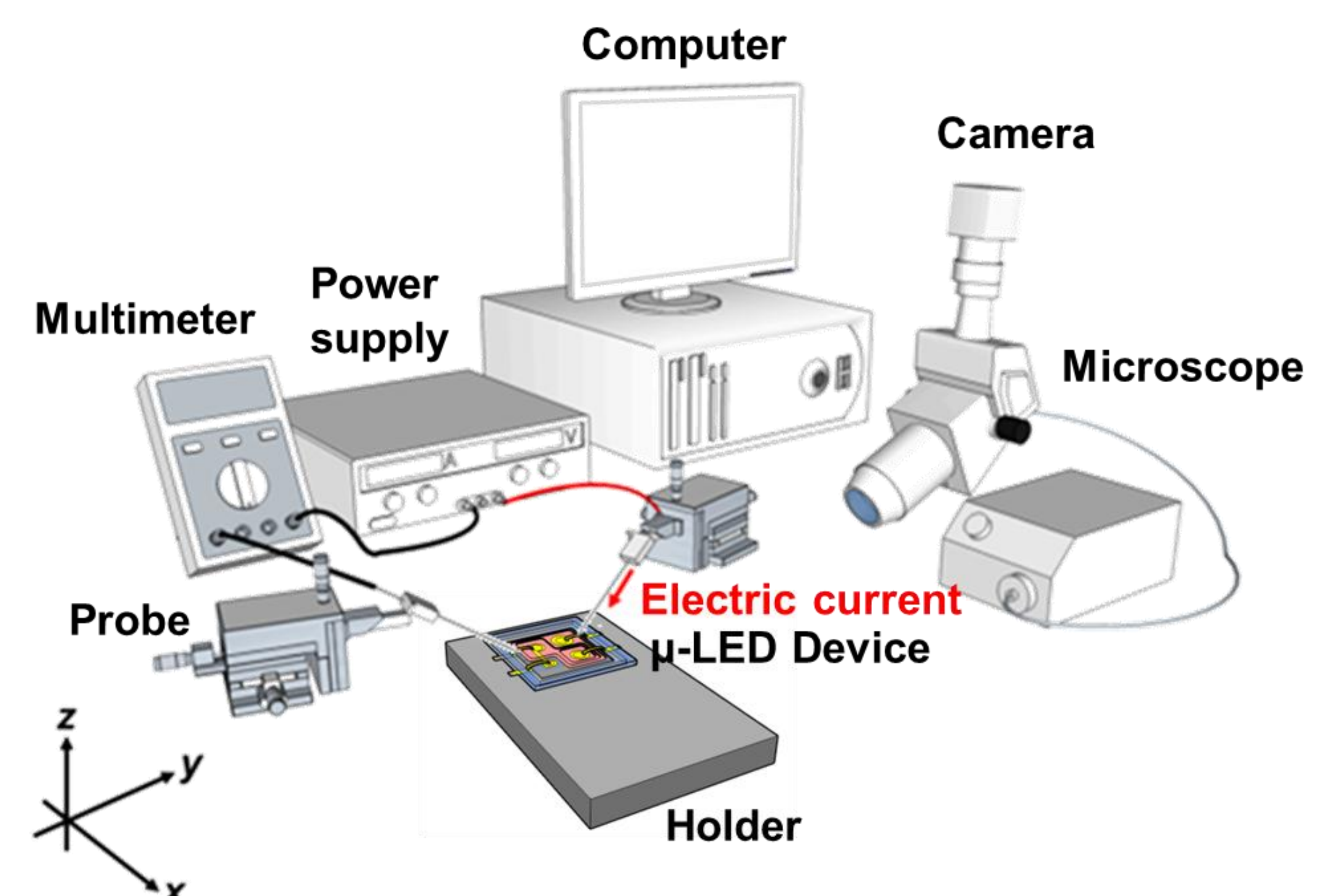


Fig. 3 Electrical Measurement Setup for μ -LEDs

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