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Diffuse Scattering from a RAFA Lens Produced High-Intensity, Far-Focused, Small 3D Virtual Source

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Since the beginning of optics whether focusing a beam by a refractive lens or reflective lens, the intensity at and close to the optic axis has not been focusable to a far, high-intensity, small three-dimensional (3D) probe due to the absence of or shallow convergence angle afforded to the lens. This limitation resulted in the formation of an elongated intensity profile along the optic axis limiting the resolution of both 3D optical imaging and 3D analytical analyses of specimens in the direction along the optic axis of the microscope (Figure 1a). This focusing limitation was significantly reduced with the invention of the RAFA lens (reflective advanced focusing aperture lens) [1]. The RAFA lens uses a 3D shaped cone reflector having a surface curved like a lens (Figure 1b). Reflection off the cone lens then requires another reflection off a flat mirror to bring the beam back to the optic axis. No intensity of the beam is lost to form the far-focused small spot now used as a 3D probe and/or a virtual source for lasers and acoustic beams. Low intensity occurs before and after the virtual source along the optic axis although diffuse scattering intensity still occurs in all directions away from the virtual source able to be used for imaging purposes.

In the optical design of Figure 1b, the highest intensity of diffuse scattering occurs at the virtual source where it scatters radially in all directions. This scattering was measured (Figure 2) as a function of distance away from the virtual source and found for an acoustic beam of ~10 W/m^2 power to extend out to ~10 cm from the virtual source above the background intensity measured in water at room temperature. Applications of this device as an acoustic medical imager will enable features deep within the body such as tumors in large breasts, up to ~20 cm diameter, and other regions of the body to be imaged.

The reflective-based RAFA lens obeys Snell's law, which focuses all wavelengths to the same focused probe position. Thus a laser beam is focused to the same spot as an acoustic beam using the same device. Multiple beams of different wavelengths can be simultaneously focused to the same focused probe position. Electron and ion beams require an electrostatic repulsive surface on the cone reflector and mirror whose potential could fluctuate with the acceleration voltage of the microscope that would enable correction of chromatic aberrations. Since the focused probe position lies on the optic axis, spherical aberration and coma are corrected. The theoretical size of the focused probe would then be determined by the planarity or flatness of the beam and its wavelength.

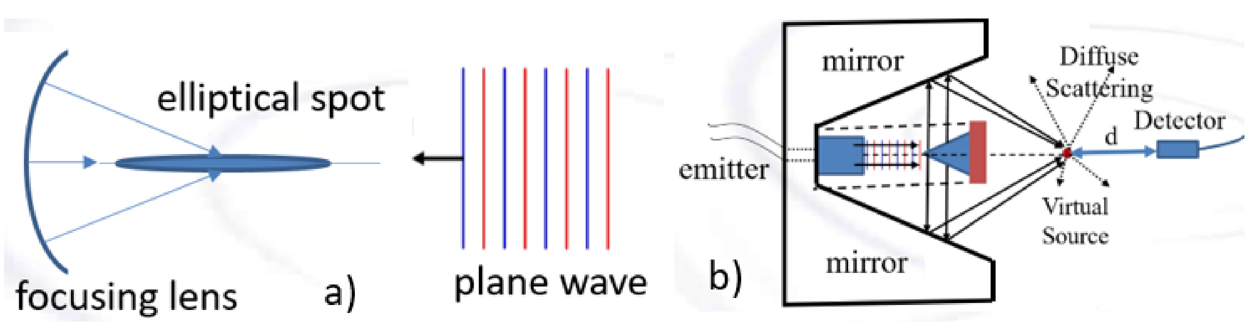

Figure 1 – a) Elliptical spot formed by a focused beam using a standard lens producing extended intensity along the optic axis, b) the RAFA lens forming a high-intensity, small spot designed to focus a beam to a distance of 10 cm from the cone lens. The focused spot was used as a virtual source. Diffuse scattering from the virtual source was measured by a detector at distances, d.

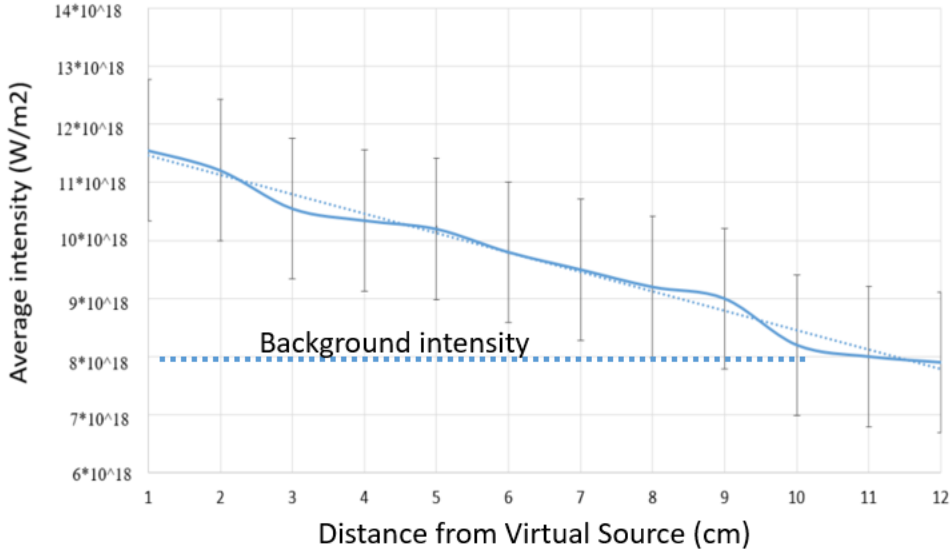

Figure 2 – Average intensity of diffusely scattered beam as a function of distance from the virtual source showing its detection above background out to ~10 cm.

References:

[1] Muniyat Rafa and Rodney Herring, RAFA Lens for Enhanced Far Focused Probes, Imaging and Analytical Resolutions, Microsc. Microanal. 27 (Suppl 1), 2021 pg. 1738/9. doi:10.1017/S1431927621006358
[2] A NSERC Discovery grant is greatly appreciated.