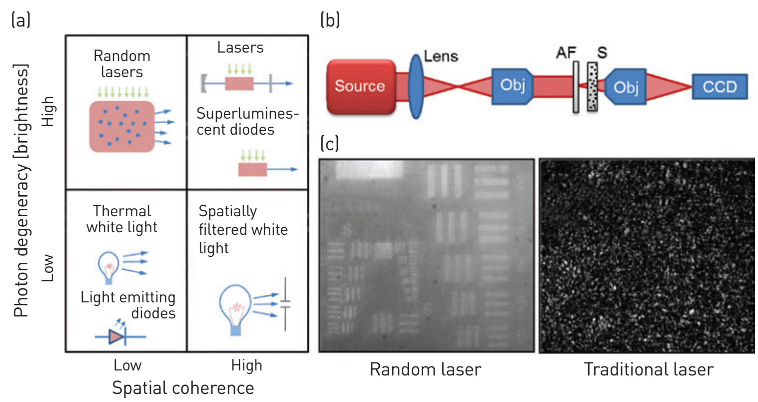
IMAGING

Speckle-Free Laser Imaging with Random Laser Illumination

Spatial coherence in imaging has one notorious consequence: speckle. It corrupts images and limits laser use in applications ranging from modern microscopy to digital light projectors to photolithography. Most approaches for eliminating speckle involve time-averaging independent speckle patterns, which limits the imaging speed. We have taken a different approach—instead of averaging out the speckle that is already present, we prevent speckle formation by using an unconventional random laser.

A random laser confines light through multiple scattering in a disordered medium.[1] Consequently, it can support a large number of spatially irregular modes that lase simultaneously and independently. The combined emission has low spatial coherence compared to conventional lasers.[2,3] In fact, by adjusting the gain volume and scattering element concentration, one can tune the spatial coherence of random laser emission over a wide range.[3] This provides a unique opportunity to design a bright illumination source whose spatial coherence is tailored for a specific imaging/projection application. We recently presented a series of imaging tests conducted with a random laser designed to produce low spatial coherence and compared the performance to illumination with several conventional sources.[4]

For each configuration we tested, the random laser illumination produced far superior images by suppressing speckle formation. Here, we show an example of imaging a U.S. Air Force (USAF) test chart through a scattering film. While a traditional HeNe laser produces high-contrast speckle that completely precludes our ability to discern the underlying object, the random laser with low spatial coherence prevents speckle formation and the chart remains visible. Although a conventional broad-band laser source can reduce the speckle contrast via spectral averaging, we demonstrated that a random laser with low spatial coherence is much more efficient in eliminating speckle.



(a) Light sources are compared by photon degeneracy and spatial coherence. (b) In the imaging test, an air force (AF) test chart was illuminated by a random or traditional laser and imaged onto a camera (CCD) through a scattering film (S). (c) The low spatial coherence of the random laser prevents the speckle that corrupts the image beyond recognition when using the traditional laser.

Adapted from B. Redding et al. Nat. Photon. **6**, 355 (2012).

The random laser produced images of similar quality to a light emitting diode (LED), which is known to have low spatial coherence. Because the random laser relies on stimulated emission, it can exhibit much higher photon degeneracy (or spectral radiance) than the LED, enabling imaging through highly dissipative media or monitoring dynamic phenomena with short integration times. Moreover, random lasers have already been realized with a host of materials, including semiconductor and fiber, operating at wavelengths across the UV, visible and IR. The ability to combine low spatial coherence with high spectral radiance—two mutually exclusive properties in conventional light sources—could enable a host of parallel imaging applications from full-field microscopy to digital light projection. OPN

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A snapshot taken with the AWARE 2 camera during a baseball game at the Durham Bulls Athletic Park. It was captured a fraction of a second after a pitch. Three areas of the scene are shown in detail. The left is from the visitors' dugout. Notice that the number on the player's jersey is clear. The middle shows the ball in flight. The right shows the stands with clearly visible fans and seats.

IMAGING

Gigapixel Imaging with the AWARE Multiscale Camera

Gigapixel cameras have been confined to specialized applications such as aerial photography and astronomical observatories.[1,2] A simplified architecture would better suit terrestrial imaging and reduce instrument cost and complexity. Our gigapixel AWARE camera is based on monocentric multiscale optical design principles that produce high-resolution images with a field of view (FOV) limited only by vignetting.[3-5] This design allows resolution to approach the theoretical diffraction limits for a given entrance pupil size and FOV.

Conventional optical systems share all components over the entire FOV. Aberrations rapidly increase in magnitude off-axis, making a large FOV and high-resolution challenging. In contrast, a multiscale camera divides the imaging task between a shared monocentric objective and a parallel array of many microcameras. The monocentric objective is a spherical lens with all surfaces sharing the same center of curvature. The objective forms an intermediate image on a spherical surface with aberrations independent of the field angle. The microcameras convey overlapping sections of the intermediate image to focal plane arrays. As the aberrations of the objective are field-angle–independent, identical microcameras may be used to cover the entire field. The microcamera images are stitched to form a gigapixel image. Because each microcamera has an adjustable focus, exposure and gain, multiscale architectures are naturally able to image high depth-of-field scenes with a high dynamic range.

The AWARE 2 monocentric multiscale camera consists of a 70-mm focal-length monocentric objective made of spherical glass elements and 98 microcameras, each of which contains a 14-megapixel monochrome CMOS sensor and an individual focus servo motor that translates the sensor for focus. The microcamera optics are molded plastic aspheric lenses. Gigapixel images are acquired by customized FPGA-based hardware. The camera fits within a 60 × 100 × 100 cm volume. OPN

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