View of the Future of Light

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Niels Bohr, the great Dane wisely noted, "Prediction is very difficult, especially about the future," while the American philosopher of the twentieth century, Yogi Berra quipped, "You can observe a lot by just watching." To be asked to write seriously about what we can expect from light-based technologies over the next hundred years is serious foolishness. With this caveat, here are some predictions of what light will allow us to see and do in that future.

The interferometers of Michelson of 100 years ago are superseded by matter interferometers that use light as beamsplitters and mirrors to measure the interference of atom matter-waves. The precision of the Michelson–Morley experiment 100 years ago saw no measurable shift of distances $\Delta l / l \sim 3 \times 10^{-9}$ parallel and perpendicular to the motion of the Earth. With atom interferometers, the precision improves by 19 orders of magnitude—the equivalent of measuring a change in the distance to the nearest star 3 light years away to one millionth of the width of a human hair. Gravity-wave astronomy becomes a reality, and space–time distortions due to quantum fluctuations of the vacuum enlarged during the epoch of inflation are mapped directly.

Photostable, near-infrared optical probes smaller than the average protein are routinely used to label and observe the molecular interactions of RNA strands and dozens of proteins simultaneously with sub-millisecond time resolution. While tissue is relatively transparent at these wavelengths, light is strongly scattered. Adaptive optics using multi-megapixel arrays and ultrafast correction methods are used to restore full optical resolution, peering centimeters into tissue. Voltage-sensitive versions of these probes record the real-time individual firing of billions of synapses in the human brain. Coupled with full knowledge of the Human Connectome, we now understand, at the circuit wiring level and at the molecular level, human consciousness and self-awareness. This understanding has allowed us to significantly slow the progression of various forms of dementia.

Optical probes allow us to track the expression levels and location of the full suite of RNA expression in time and space within individual cells in live tissue. DNA sequencing identification methods based on optics help us identify many diseases and greatly reduce misdiagnoses. Optical methods of understanding the genetic mutations that cause many cancers are routinely used to develop targeted drug therapies and in helping recruit the human immune system to cleanse the body of oncogenes with minimal side effects.

To handle the stupendous computing needs of the achievements listed above, quantum computers, quantum simulators, and nanoscale memory are widely used. We use them to simulate complex systems with sufficient detail to discover improved room temperature superconductors. We use this computational prowess to understand how our brains perceive and how we analyze and respond to stimuli, as well as to perform massive simulations that reliably predict climate change caused by human-generated greenhouse gas emission.

Solar power is the lowest-cost source of energy in many parts of the world. This energy is beginning to be distributed across oceans via ultra-high DC voltage lines in undersea cables capable of moving tens of gigawatts of power greater than 4000 km with less than 5% loss. Regions of the world with poor solar irradiation and reduced winter solar generation are supplied with clean energy.

Unfortunately, the integrated carbon emission by 2065 was not reduced quickly enough. With our deeper understanding of climate change, the errors of not heeding early warning signs are starkly seen. The advanced visible and infrared Earth monitoring sensors and orbiting atom-wave gravity gradiometers allow us to measure with remarkable precision how the climate is changing. The demonstration of reliable long-term weather predictions allows us to forecast with confidence the climate of 2100 and 2200. Just as exposure to carcinogens such as asbestos or cigarette smoke can trigger a series of multiple mutations that lead to cancer many decades later, we now realize that greenhouse gas emissions put our world on an extremely disruptive and destructive course for a significant fraction of the population.

Is this last prediction too dire? Possibly, but I also believe there is hope. While science alone will not change political policy, the massive use of optical technologies will provide compelling evidence (and compelling predictions) to convince a vast majority of people and governments of the world to make the necessary investments for future generations. In addition, the near future is ripe with the promise of understanding the human brain and body at breathtaking new levels, again with optics-enabled technologies. These advances will not only lead to better health and longer and better life spans. With our optics-enhanced ability see the future, we will likely observe that global altruism and compassion will serve our own self-interest exceedingly well.

Of course, what happens beyond 50 years is very difficult to predict. The first power flight by the Wright Brothers was in 1903, and we landed men on the moon in 1969. All that can be reliably foreseen is that there will be many wondrous surprises in optics in the next 100 years.