Integrated Neurophotonics: A new, all-optical paradigm for dense brain circuit interrogation at arbitrary depths

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Although our understanding of the properties of individual neurons and their role in brain computation has advanced significantly over the past several decades, we are still far from elucidating how complex assemblies of neurons – that is, brain circuits – interact to process information (Fig. 1). In 2011, six U.S. scientists from different disciplines banded together, outlined a vision [1,2], and managed to convince the Obama administration's White House office of Science and Technology Policy (OSTP) of the unprecedented opportunity that exists to launch a coordinated, large-scale international effort to map brain activity. This culminated in the U.S. BRAIN Initiative (Brain Research through Advancing Innovative Neurotechnologies), which was launched in 2013. Our perspective was predicated, in part, on the current level of maturity of diverse fields of nanotechnology and silicon-based very-large-scale integration (VLSI) that can now be coalesced to create unprecedented tools for massively parallel interrogation of brain activity. I will outline the immense complexity of such pursuits, the hopes we articulated, survey the existing technological landscape for assembling the requisite instrumentation, and then focus upon our collaborative efforts toward tools enabling multi-physical interrogation of brain activity. Especially promising is a new technological field we are calling integrated neurophotonics, which merges advances in photonic circuit VLSI with optogenetic molecular reporters and actuators.* We believe this new technology will engender a wide spectrum of unprecedented possibilities for both fundamental neuroscience and clinical neuromedicine

This work is being carried out in close collaboration with Professors Kenneth Shepard (Columbia University), Joyce Poon (University of Toronto), and Andreas Tolias (Baylor College of Medicine) – and members of our research groups.

References

[1] Alivisatos A.P., Chun M., Church G.M., Greenspan R.J., Roukes M.L., Yuste R., The Brain Activity Map project and the challenge of functional connectomics. Neuron 74, 970-974 (2012).

[2] Alivisatos A.P., Chun M., Church G.M., Greenspan R.J., Roukes M.L., Yuste R., A National Network of Neurotechnology Centers for the BRAIN Initiative. Neuron 88, 445-448 (2015).

Figures

Figure 1. Portion of a mid-sagittal section of transgenic mouse brain imaged by confocal microscopy, with neurons color-coded for depth. credit: Dr. Laurent Moreaux (Caltech) and Dr. Stephan Junek (Max Planck Institute for Brain Research).