David A. B. Miller

In a career spanning more than 45 years, David Miller has made many key contributions in original scientific and engineering research, in education, and in professional service. His research is characterized by leading and highly cited contributions and substantial bodies of work in each of several areas, including semiconductor and quantum well optoelectronics; optics in digital systems, information processing, and communications; fundamentals of optics and waves; and complex and controllable photonic circuits. His work on the discovery, physical explanation and device application of the quantum-confined Stark effect in semiconductor quantum wells is used extensively to modulate the signals in optical fiber communications. His analytic and experimental work on optics in digital systems stimulated and underpins the growing field of optical interconnects. His introduction of a new modal analysis of optics and waves is seeing increasing use in wireless and optical communication systems, with several novel fundamental physical results. His invention of universal and self-configuring interferometric optical circuits and their architectures and algorithms has stimulated the growing field programmable photonics. His professional service includes extensive work in conferences and in professional societies, including a society presidency. In addition to his university teaching and his lecturing in short courses and schools, his educational work in quantum mechanics has impacted more than 80,000 students worldwide through his open online courses and his textbook.

Degrees, appointments, fellowships, and awards

He holds a B. Sc. from St. Andrews University and a Ph.D. from Heriot-Watt University, both in Physics. He has been the W. M. Keck Professor of Electrical Engineering (Emeritus since Oct. 2024), and Professor by Courtesy of Applied Physics at Stanford University. Before Stanford, he was with Bell Laboratories from 1981 to 1996, as a department head from 1987. He was awarded the OSA Adolph Lomb Medal and the R. W. Wood Prize, the ICO International Prize in Optics, the IEEE Third Millennium Medal, and the 2013 Carnegie Millennium Professorship. He is also a Fellow of AAAS, APS, OSA, IEEE, the Electromagnetics Academy, the Royal Society of London and the Royal Society of Edinburgh, holds two Honorary Doctorates, and is a Member of the US National Academies of Sciences and of Engineering.

Research contributions

Semiconductor optics and optoelectronics

Working with his Bell Labs colleagues, especially Daniel Chemla and Art Gossard, and later also Wayne Knox and Stefan Schmitt-Rink, David Miller discovered and exploited many remarkable optical properties of quantum well semiconductor structures. In particular, they discovered, explained and named the Quantum-Confined Stark Effect (QCSE) [1,2], a very large and fast room-temperature quantum mechanical effect that enables high-speed, low-power optical modulators. Such modulators are now used extensively in modern optical telecommunications and the internet, being one of the major ways of putting information onto light in optical fibers. The underlying physics is now a textbook piece of quantum mechanics and is an important mechanism also in visible light-emitting diodes. Later work at Stanford, especially with Yu-Hsuan Kuo and Jim Harris [3], extended this to germanium-based quantum wells on silicon substrates that promise high-performance modulators compatible with silicon photonics and CMOS electronics.

In their joint work at Bells Labs, he and his colleagues clarified optical and excitonic physics in quantum wells, including explaining the strong excitonic effects and various related electro-optic, absorption saturation [4], and ultrafast and nonlinear optical processes in quantum wells and quantum dots [5], including their ultrafast dynamics [6] (see the reviews [7,8]), and charge [9] and Bloch oscillations [10] in quantum wells and superlattices. The work on absorption saturation led to successful mode-locking of semiconductor lasers, in work especially with Yaron Silberberg and Peter Smith [11], and later in contributions to the work of Ursula Keller on mode-locking of solid-state lasers [12].

Optics in digital systems

Through his discoveries, inventions, analysis, reviews, and collaborations, David Miller's work led to extensive activity in the field of optics in digital systems. As well as clarifying the opportunities and challenges of optical logic, his extensive work in optical interconnects stimulated and underpinned this growing field.

Optical logic

His discovery, in his thesis work at Heriot-Watt University with S. Des Smith, of large nonlinear optical effects in the semiconductor InSb [13] led to his demonstration of optical bistability and switching in a semiconductor structure [14]. This demonstration, and the simultaneous demonstration of optical bistability in GaAs by Hyatt Gibbs and others at Bell Labs [15] (both papers were submitted to the same journal on the same day) stimulated increasing interest in ideas of optics in digital systems. The use of the QCSE together with local optoelectronic feedback in "self-electrooptic-effect devices" (SEEDs) that he invented [16], provided a low-energy approach to optical logic, and allowed the more sophisticated operations [17] required for viable logic systems. Work with Bell Labs colleagues, especially Tony Lentine [17] and Scott Hinton [18], led to successful large-scale demonstrations of working digital optical systems with many 10,000's of light beams [18] and, with Alan Huang and colleagues, broader consideration of digital optical systems [19]. This work exposed both the challenges and limitations of optical logic, as he pointed out explicitly in [20], and later, in what has become a definitive reference on the topic, [21]. This work also generated the idea of "smart pixels" that would embody the best of both the optical and electronic technologies [17,22], and helped stimulate increasing interest in the remarkable and unique benefits of optics for interconnection, as discussed next.

Optical interconnects

David Miller's work in optical interconnects is arguably responsible for clarifying why and how optics are essential for reducing energy and increasing density for interconnects inside machines, how this can be achieved technologically, and why optical interconnects may be the only approach that can allow interconnects, especially between chips and beyond, to scale to keep up with ever growing demand. As a result of these benefits, optical interconnects are increasingly essential in data centers and for emerging applications like artificial intelligence.

In basic investigations into optical interconnects inside digital machines, David Miller showed, first of all, why optics fundamentally can save energy in interconnections [23], for a reason that comes from quantum mechanics, and later clarified device energy consumption limits [24]. With Haldun Ozaktas, he showed why optics overcomes basic bandwidth density limitations of electrical wiring [25], limitations that already exist in current machines. He summarized these and other physical reasons for optical interconnection in a key paper [26]. With Ashok Krishnamoorthy, he showed that the integration of photodetectors close to transistors would be key to enabling low-energy optical interconnections [27]. In a series of definitive review articles [28–30] that have become authoritative references in the field, cited over 6000 times, he summarized and expanded on the reasons for optical interconnects and the technological requirements and progress to implement them.

With his students, he also made several key experimental demonstrations. Especially with Gordon Keeler, Bianca Nelson and Diwakar Agarwal, he pioneered wavelength-division multiplexed interconnects between chips [31] and showed synchronization advantages of optical connections [32]. Especially with Aparna Bhatnagar, Christof Debaes and Salman Latif, he investigated the possibilities for precise clock injection using optics [33], and, especially with Ryohei Urata, precise sampling timing in analog to digital conversion [34].

Fundamentals of optics and waves

David Miller has made several key contributions to our understanding of waves generally, especially in clarifying the channels for communicating with waves. His first work in this field was an extension of Huygens' principle of wave propagation [35]. This understanding led later to his proof of the impossibility of cloaking and invisibility from pulsed waves [36], together with a definitive statement of the required sources for practical cloaking. A major contribution has been his introduction of the idea of communication modes, starting in 1998 [37–39]. This approach shows how to find the orthogonal channels between sources in one volume and the resulting "received" waves in another. It exploits singular-value decomposition (SVD) of the coupling between sources in one volume and the resulting waves in another. It goes beyond conventional diffraction theory to cover arbitrary volumes. It found its first uses by others in wireless communications (see [39] for a review), where it gives a rigorous way to establish and count channels. Its use in optics and wireless has grown steadily since. He extended it to the idea of mode-converter basis sets [40], which are an optimal wave to describe a linear optical device. This approach leads to several fundamental results, including the extension of Kirchhoff's radiation laws [41] to nanostructures and non-reciprocal optics, a simpler, modal form of Einstein's A&B coefficient argument [39], and a sum rule that is a generalization of diffraction limits to arbitrary structures (see [39] for a review). This modal approach, together with a fundamental approach to complexity in optics [42], also clarifies limits in optics [43,44], including slow-light devices [44]. Recent work (published as a single-author paper in Science [45]) based on his communication mode approach, shows why optics needs thickness, explaining fundamentally why many existing and novel devices have difficulty reducing thickness, and giving clear guidelines for design.

Other early influential work in optics has been the first proposal of an approach for time-reversing waves in optics [46], and the general topic of measuring nonlinear optical processes by beam distortion [47], which was a precursor to the later z-scan measurement techniques introduced by others.

Complex and controllable photonic circuits

David Miller's work has played a seminal role in the emergence of complex, functional optical systems in inverse-designed nanophotonics and in programmable optics.

Inverse design

With his student Martina Gerken, he designed and demonstrated what may be the first nanophotonic structure inverse-designed for a desired function (wavelength separation) [48,49], and with his student Yang Jiao, and with Shanhui Fan, he proposed the first inverse-designed mode-splitter [50]. Such inverse designs are characterized by extreme compactness as well as surprising behavior from non-intuitive structures. Stimulated in part by this work, this field has grown substantially since then (see, e.g., the review by Molesky at al. [51]).

Arbitrary and programmable optics with interferometer meshes

David Miller introduced the idea of universal linear optical machines [52], both as a theoretical construct for fundamental optical physics (used, e.g., in the proof of new radiation laws [41] and simplified, modal "A&B" coefficient arguments [39]), and as a practical approach for novel optical systems. He showed how any such machine could be constructed from two-beam interferometers, including practical methods based on Mach-Zehnder interferometers, e.g., in silicon photonic integrated circuits, arguably starting the field of programmable silicon photonics for applications in optics itself (see, e.g., the review [53] co-written by David Miller). This work also introduced the practical algorithms and architectures that allow simple, automatic self-configuration and stabilization of such complex interferometric systems (see also [54–56]), and proposed applications in optical information processing and communications that have subsequently been successfully demonstrated, by him and his collaborators (e.g., [57–61]) and others [53].

His proposed algorithms in his architectures allow self-configuration without calibration or even external calculation. Various such automatic functions since demonstrated in silicon photonic circuits in collaborations with colleagues at Politecnico di Milano (especially Francesco Morichetti and Andrea Melloni and their students), include automatic separation of overlapped light beams [57,58] and the automatic establishing of the best, orthogonal optical channels through arbitrary optics [59], again without external calculations.

In collaboration with Olav Solgaard and his students, especially Sunil Pai, this work has been extended to implement novel matrix-based computations in the optical domain [60,61], including implementing back-propagation learning in optical neural systems [60], based on a proposal by Shanhui Fan and his students. The universal singular-value decomposition (SVD) architecture he introduced [52] has also been used by others for key demonstrations in optical neural networks [62].

Other contributions

David Miller and his collaborators have made significant contributions in many other areas of optics and optoelectronics, including nonlinear optics in semiconductors [63], and nanometallic waveguides [64] and antennas [65] in optoelectronics.

Citation record

David Miller has published over 300 papers. He has collaborated widely and successfully, co-authoring publications with over 400 individuals, including supporting work by and with his students and many others. He also has amassed a substantial body of individual work throughout his career. He is the first or sole author on his 4 most cited papers. Of his 52 publications cited 250 times or more, he is the sole author on 14, and the first author on a further 8. Overall, he has published over 40 single-author refereed papers, as well as a textbook. In addition to journal publications, he has been an inventor on 78 US patents, with 57 co-inventors, and is a sole inventor on 21.

His h-index is 114, and his work has been cited more than 55,000 times. As a first author (including sole-author papers), his h-index would be 58. As a single author, his work has been cited over 12,000 times and his corresponding h-index for these publications alone would be 42. (All numbers from Google Scholar statistics as of April 2024.)

Professional service

David Miller served in various volunteer roles in professional societies, including on the Board of OSA (now Optica), and in the IEEE Lasers and Electro-Optics Society (now IEEE Photonics Society), where he ultimately served as President in 1995. He participated in over 40 conference committees, including serving as a General Chair of the major CLEO conference. He has served on many external advisory boards for university research programs and on government advisory bodies. At Bells Labs, he served as a Department Head for 9 years. At Stanford, he served in leadership roles within the Electrical Engineering department, and as the Director of the Ginzton Laboratory for 9 years and of the Stanford Photonics Research Center for 19 years.

Educational contributions

David Miller has taught various engineering and physics subjects, at Heriot-Watt University in the UK in his early career, and later at Stanford University. His courses have covered electromagnetism, statistical mechanics and thermodynamics, semiconductor physics, optoelectronic device principles and applications, optics, and quantum mechanics. He has also taught more than 45 short courses at major conferences and workshops, especially on quantum well optoelectronics, on optics in information processing and interconnects, and on fundamentals of complex optical systems. He has presented 15 tutorials at major conferences and has lectured at 21 different summer schools.

He wrote the text *Quantum Mechanics for Scientists and Engineers* (Cambridge 2008), which is now used in many universities. A particularly important contribution has been his sequence of two online courses, “Quantum Mechanics for Scientists and Engineers, 1 and 2”. Created originally in 2013 and 2014, these have been revised and expanded since then, and have been taken by over 80,000 students worldwide. These courses are available at no cost, and all the lecture videos and slides are also posted openly.

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