Progress in Microwave Photonics

Alwyn J. Seeds*(1), Katarzyna Balakier(1), Cyril Renaud(1), James Seddon(1), Chris Graham(1), Lalitha Ponnampalam(1), Michele Natrella(1)
(1) Dept. of Electronic and Electrical Engineering, University College London, Torrington Place, London, WC1E 7JE, UK, e-mail: a.seeds@ucl.ac.uk

Extended Abstract

Microwave photonics can be defined as the study of opto-electronic devices and systems processing signals at microwave frequencies and the use of opto-electronic devices and systems for signal handling in microwave systems [1]. Its origin as a research field dates from the invention of the laser in 1960, with microwave bandwidth optical modulators being reported by 1962 [2]. The demonstration of the room temperature semiconductor laser in 1964 [3, 4] gave further impetus to the field, due to its compact size, potentially low cost and its GHz bandwidth direct modulation capability by varying the pumping current [5]. Microwave bandwidth photodiodes were developed by the early 1960s [6]. The final essential ingredient was the invention of the low loss optical fibre waveguide in 1966 [7] for which Charles Kao was awarded the Nobel Prize in Physics in 2009. Intensive work on the reduction of impurities in silica led to single mode optical fibres with losses < 0.2 dB/km, far lower than waveguides at microwave frequencies and with vastly greater bandwidth, > 10 THz. Progress in microwave photonics has built on these technologies to create systems for the remoting of microwave antennas [8], which have replaced metallic transmission lines and are now used worldwide, including extensive deployments to provide cellular radio coverage in tunnels, large buildings and other locations where coverage from external base stations is limited. Progress in laser frequency control and the control of laser emission linewidth has made it feasible to synthesize spectrally pure (Hz linewidth) signals at THz frequencies allowing the transmission of wireless signals with data rates exceeding 100 Gb/s [9]. A key area for future advances is photonic integration as a driver for reduced systems cost. Important demonstrations have already taken place using InP technology [10] and the pioneering demonstration of lasers directly integrated on silicon [11] offers the potential for larger scale integration at greatly reduced cost.

References

[1] A. J. Seeds and K. J. Williams, "Microwave Photonics" *Journal of Lightwave Technology*, **24**, 12, 2006, pp. 4,628-4,641.

[2] R. H. Blumenthal, "Design of a microwave frequency light modulator," *Proc. IRE*, **50**, 4, 1962, pp. 452–456.

[3] I. Hayashi, M. B. Panish, P. W. Foy, and S. Sumski, "Junction lasers which operate continuously at room temperature," *Appl. Phys. Lett*., **17**, 3, August 1970, pp. 109–111.

[4] Z. I. Alferov, V. M. Andreev, D. Z. Garbuzov, Y. V. Zhilyaev, E. P. Morozov, E. L. Portnoi, and V. G. Triofim, "Investigation of the influence of the AlAs-GaAs heterostructure parameters on the laser threshold current and the realisation of continuous emission at room temperature," *Fiz. Tekh. Poluprovodn*., **4**, 9, 1970, p. 1826.

[5] T. Ikegami and Y. Suematsu, "Resonance-like characteristics of the direct modulation of a junction laser," *Proc. IEEE*, **55**, 1, January 1967, pp. 122–123.

[6] R. P. Rietz, "High speed semiconductor photodiodes," *Rev. Sci. Instrum*., **33**, 9, 1962, pp. 994–999.

[7] K. C. Kao and G. A. Hockham, "Dielectric-fiber surface waveguides for optical frequencies," *Proc. Inst. Electr. Eng.*, **133**, 3, July 1966, pp. 1151–1158.

[8] A. J. Seeds, "Optical transmission of microwaves," in Review of Radio Science, W. R. Stone, Ed. Oxford, U.K.: Oxford Univ. Press, 1996, pp. 325–360.

[9] A. J. Seeds, H. Shams, M. J. Fice, and C. C. Renaud, "TeraHertz photonics for wireless communications," *Journal of Lightwave Technology*, **33**, 3, 2015, pp. 579-587.

[10] K. Balakier, M. J. Fice, L. Ponnampalam, A. J. Seeds and, C.C. Renaud, "Monolithically integrated optical phase lock loop for microwave photonics," *Journal of Lightwave Technology*, **32**, 20, pp. 3893-3900.

[11] S. Chen, W. Li, J. Wu, Q. Jiang, M. Tang, S. Shutts, S. N. Elliott, A. Sobiesierski, A. J. Seeds, I. Ross, P. Smowton, H. Liu, "Electrically pumped continuous-wave III–V quantum dot lasers on silicon," *Nature Photonics*, **10**, 2016, pp. 307–311.