Integrated Microwave Photonic Radars: Recent Advances, Challenges, and Future Perspectives

Simin Li, Mengya Zong, Yu Zhang, Dezhe Yuan, Ming Li, Jijun He and Shilong Pan, *Fellow, IEEE, Fellow, Optica*

(Invited Paper)

***Abstract*—This paper presents a review of the state-of-the-art progress in integrated microwave photonic radar chips. Two representative architectures are introduced: one is based on photonic frequency multiplication for signal generation and photonic de-chirping for signal processing (FMPD), and the other is based on optical up-/down-conversion (OUDC). Their operational principles, merits, drawbacks, and recent advances are analyzed. In addition, the advanced chips characterized by multi-band fusion, multi-channel integration, and radar-lidar co-design are discussed, together with heterogeneous integration technologies (e.g., photonic wire bonding, micro-transfer printing) that mitigate the inherent limitations of single-platform integration. Critical challenges in this field are also identified, including performance shortcomings, integration bottlenecks, packaging complexity, and functional immaturity. Finally, the future development trends toward high-density integration, functional convergence, and practical deployment are outlined and prospected.**

***Index Terms*—microwave photonic radar, integrated microwave photonics, photonic integrated chip.**

I. INTRODUCTION

RADAR, as the only sensor capable of all-weather and day-and-night operation, plays an indispensable role in both defense and civilian applications. Through the transmission and reception of electromagnetic waves, it acquires target information such as spatial position, velocity, and radar imagery. The pursuit of higher resolution, referring to the ability to distinguish more closely spaced targets, has been a key driving force for the advancement of radar technology. According to the radar resolution theory, range resolution is inversely proportional to the instantaneous bandwidth of the transmitted signal. Consequently, achieving centimeter-level or even millimeter-level resolution necessitates the generation and processing of ultra-wideband microwave or millimeter-wave signals with bandwidths ranging from several to tens of gigahertz. Moreover, emerging application platforms with stringent size constraints, such as unmanned aerial vehicles, automobiles, and robots, place strict requirements on the size, weight, power consumption, and cost of radar systems. However, conventional electronic radar systems encounter substantial challenges in generating and processing such ultra-wideband waveforms. These challenges primarily stem from the inherent limitations of electronic components, including bandwidth bottlenecks, frequency-dependent losses, severe electromagnetic interference, and the accompanying rise in system complexity and manufacturing cost.

Microwave photonics (MWP), an interdisciplinary field that utilizes photonic technologies for the generation, processing, manipulation, and transmission of microwave signals, has emerged as a promising solution to break through electronic bottlenecks [1], [2]. According to a previous study [3], microwave photonics can bring several pivotal performance improvements to radar systems: the realization of ultra-low phase noise optoelectronic oscillators (OEOs) serving as radar local oscillator sources, effectively lowering the system noise floor and enhancing the detection capability of weak signals under strong clutter backgrounds; the capacity to generate and process ultra-wideband radar waveforms with bandwidths extending from several gigahertz to tens of gigahertz, thus drastically improving radar range resolution; the provision of flexible frequency tunability, enabling rapid frequency switching and cooperative operation across diverse radar frequency bands; the implementation of optically controlled beamforming networks (OBFNs) based on optical delay tuning, which can effectively suppress the beam squint effect in wideband signals and enable distortion-free beam scanning; the facilitation of frequency-independent, low-loss long-distance signal transmission via optical fibers, supporting the construction of large-scale, highly synchronized distributed radar networks, expanding detection coverage, and enhancing system redundancy and survivability; and the inherent immunity to electromagnetic interference, boosting system reliability in complex electromagnetic environments. Over the past decade, these unique merits have significantly promoted the development of photonics-based radar systems.

In 2014, a fully photonics-based coherent radar system was demonstrated [4], which for the first time implemented microwave photonic technology throughout the entire chain of radar signal generation and echo processing. Subsequently, a variety of microwave photonic radar architectures have been proposed and validated [5], [6], [7], [8], [9], [10], [11]. With the continuous evolution of this technology, microwave photonic radars have evolved from primitive single-channel

Received xx xx 2026; revised xx xx 2026; accepted xx xx 2026. Date of publication xx xx 2026; date of current version xx xx 2026. This work was supported by the National Natural Science Foundation of China (62213142).
(Corresponding author: Shilong Pan). The authors are with the National Key Laboratory of Microwave Photonics, Nanjing University of Aeronautics and Astronautics, Nanjing 211106, China (e-mail: lisimin@nuaa.edu.cn; myzong@nuaa.edu.cn; yu-zhang@nuaa.edu.cn; mwp_ydz@nuaa.edu.cn; lm3773ml@nuaa.edu.cn; jijun.he@nuaa.edu.cn; pans@nuaa.edu.cn)

This article has been accepted for publication in Journal of Lightwave Technology. This is the author's version which has not been fully edited and content may change prior to final publication. Citation information: DOI 10.1109/JLT.2026.3713375

architectures to sophisticated system configurations, featuring multi-band cooperative detection [12], distributed networking [13], multiple-input multiple-output structures [14], or adaptive cognitive capabilities [15], which significantly enhance resolution, anti-interference performance, and target recognition accuracy. Recently, leveraging the advantages of microwave photonics in spectral flexibility and signal reconstruction, radar and wireless communication functions are gradually converged to develop multifunctional integrated systems [16].

Although these pioneering microwave photonic radar systems have been validated in laboratory environments, most of them are constructed using massive discrete photonic and electronic components, resulting in bulky volume, heavy weight as well as unsatisfactory long-term operational stability. These inherent drawbacks severely restrict their practical deployment in strict space- or weight-constrained and high-reliability application scenarios, such as unmanned aerial vehicles, vehicle-mounted sensing systems, and space-borne platforms. In contrast to conventional approaches that rely on discrete optical and electronic modules interconnected via complex cables, integrated photonic technologies can consolidate core functional elements, including lasers, modulators, photodetectors (PDs), passive photonic devices, and even radio frequency (RF) chips, into compact modules or monolithic chips through co-design and advanced packaging methodologies. This approach substantially reduces the number of individual components and the complexity of interconnection structures, thereby enabling significant reductions in system size and weight while significantly improving overall operational stability and reliability. Accordingly, integration is not merely an optional improvement for next-generation microwave photonic radar systems, but rather the essential pathway and core objective for transforming these systems from laboratory prototypes to practical deployment and real-world engineering applications.

Driven by this critical demand, extensive research efforts have recently been devoted to the development of integrated microwave photonic radar chips. By utilizing advanced photonic integration platforms such as silicon-on-insulator (SOI), thin-film lithium niobate (TFLN), and indium phosphide (InP), researchers have successfully integrated fundamental functional building blocks, including core modules such as OEOs [17], [18], [19], [20], radar waveform generators [21], [22], [23], [24], OBFNs [25], [26], [27] and optical analog-to-digital converters (ADCs), [28], [29]. Correspondingly, considerable progress has been achieved in integrated photonic modules for radar signal measurement and processing, such as instantaneous frequency measurement [30], [31], [32], [33], Doppler frequency shift measurement [34], and multi-parameter measurement [35]. Notably, significant breakthroughs have been realized in on-chip radar systems with complete signal transmission and echo processing capabilities, marking a critical step forward for microwave photonic radar from discrete devices towards integrated system-level solutions.

This paper presents a comprehensive review of recent state-of-the-art research progress in microwave photonic radar chips. Section II introduces two typical architectures for implementing microwave photonic radar chips. Subsequently, Section III summarizes the advanced developments based on the basic architectures, inculding technologies such as multi-band radar, multi-channel radar, and radar-lidar integration. Section IV further explores the heterogeneously integrated microwave photonic radars. Finally, Section V analyzes the key challenges and prospects future development directions for integrated microwave photonic radar chips.

II. Architectures of Microwave Photonic Radar Chips

In general, the architectures of microwave photonic radar chips can be classified into two categories: one based on photonic frequency multiplication for signal generation and photonic de-chirping for signal processing (FMDP), and the other based on optical up-/down-conversion (OUDC) to construct a wideband transceiver.

A. Frequency multiplication and de-chirping processing (FMDP) architecture

Figure 1 (a) depicts the most prevalent architecture for implementing a microwave photonic radar on a chip. This architecture employs electro-optic modulation to generate high-order sidebands, thereby creating a frequency-multiplied linear frequency-modulated (LFM) signal for transmitting. Additionally, it mixes the received echo with the transmitted signal in the receiver for de-chirping.

Assume that the input LFM signal is represented as

$$f_{\text{IF}}(t) = f_0 + kt = f_0 + \frac{B}{T}t \,, \tag{1}$$

where f_0 and k denote the initial frequency and chirp rate, T and B represent the pulse width and bandwidth of the LFM signal. The radar range resolution can be expressed as

$$R = \frac{c}{2B}, \tag{2}$$

where c is the speed of light.

Given that the radar range resolution is inversely proportional to the bandwidth of the transmitted signal, the utilization of frequency multiplication enables the generation of radar transmit signals with a large bandwidth, thereby enhancing the radar resolution.

By applying photonic frequency multiplication with a factor of N, the generated LFM signal becomes

$$f_{\text{T}}(t) = Nf_0 + Nkt = Nf_0 + \frac{NB}{T}t \,, \tag{3}$$

This signal not only exhibits an expanded bandwidth but also an increased carrier frequency. The theoretical range resolution is improved to

$$R_{\text{enhenced}} = \frac{c}{2NB}, \tag{4}$$

In the de-chirping process, the received echo signal with a time delay τ is mixed with the transmit LFM signal in the optical domain. The resulting de-chirped signal has a beat frequency Δf that is proportional to τ,

$$\Delta f = N \cdot k \cdot \tau \, . \tag{5}$$

By leveraging this relationship, the time delay, and consequently the target range, can be accurately estimated from the low-frequency de-chirped signal through spectral analysis. This de-chirping process effectively converts the wideband echo into a narrowband signal, significantly reducing the sampling rate required for the ADC. As a result, it facilitates real-time, high-resolution radar signal processing.

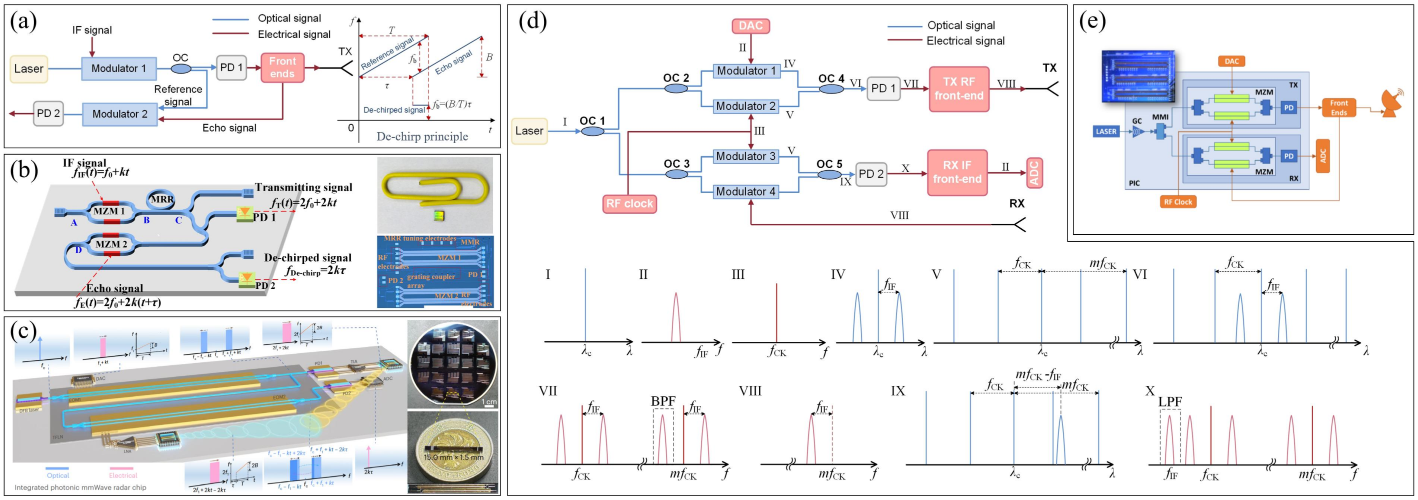

Fig. 1. (a) Principle of a typical microwave photonic radar chip based on FMDP architecture; (b) Schematic diagram and chip photograph of the FMDP SOI microwave photonic radar chip [36]; (c) Schematic diagram and chip photograph of the FMDP TFLN microwave photonic radar chip [37]; (d) Principle of a typical microwave photonic radar chip based on OUDC architecture; (e) Schematic diagram and chip photograph of the OUDC SOI microwave photonic radar chip [38].

In 2019, a FMDP microwave photonic radar chip was demonstrated on an SOI platform [36]. As depicted in Fig. 1(b), the chip integrates two Mach-Zehnder modulators (MZMs), a microring resonator filter, and two PDs within a compact area of merely 1.45 mm × 2.5 mm. One MZM produces ±1st-order sidebands and one PD beats them to generate a frequency-doubled microwave signal. The microring is utilized to enhance carrier suppression. Experimentally, the system generated a transmit signal covering the entire Ku-band (12–18 GHz) with a 6-GHz bandwidth, while keeping in-band power fluctuations within ±1 dB. By leveraging this signal, the radar attains high-precision ranging with an error of less than 2.75 mm and high-resolution imaging with a range resolution of 2.7 cm. Successful inverse synthetic aperture radar (ISAR) imaging was demonstrated for targets with multiple reflective points, i.e., an alphabet "A" array and an aircraft model.

Subsequent research has advanced beyond silicon photonics by exploiting materials with superior electro-optic properties, such as TFLN. A prominent example is an integrated FMDP millimeter-wave radar system, fabricated on a TFLN photonic chip using a 4-inch wafer-scale process, as shown in Fig. 1 (c) [37]. Operating in the V band (40–50 GHz), this system experimentally achieved multi-target ranging (1.50 cm resolution), velocity measurement (0.067 m/s resolution), and ISAR imaging with a two-dimensional resolution of 1.50 cm × 1.06 cm.

The two cases described above both adhere to the classical cascaded architecture, which comprises a transmitter modulator and a receiver modulator, inherited from discrete systems. In discrete implementations, the high-order optical sidebands generated by the transmitter modulator can function as optical local oscillator (LO) signals. These signals can be power-amplified via erbium-doped fiber amplifiers before being injected into the receiver, thereby ensuring sufficient mixing efficiency.

Conversely, integrated chip solutions encounter the challenge of underdeveloped on-chip optical amplification technologies. This limitation results in weaker optical LO power at the receiver input and constrains the feasibility of effective on-chip compensation. This constraint directly affects the receiver's dynamic range and signal-to-noise ratio (SNR). A viable approach to alleviate this issue in current practice is to adopt separated transmit–receive light sources, i.e., at the receiver end, the optical carrier (OC) is input via an independent light source, with the transmitted signal and the echo signal separately modulated onto the two arms of an MZM. Alternatively, the two signals can be combined electrically before modulation onto the receiver's.

Moreover, integrated solutions frequently employ frequency-doubling architectures, which represent a practical trade-off between complexity and system performance. In discrete systems, more sophisticated configurations, such as dual-parallel MZMs, can achieve quadruple or even higher-order frequency multiplication. This facilitates the generation of high-frequency millimeter-wave signals using low-frequency electronic components and further improves radar resolution. Nevertheless, the implementation of high-order frequency multiplication in integrated photonic chips presents several challenges. These challenges include increased chip area and power consumption, which arise from complex optical circuitry, multiple modulation stages, and precise bias control. They also involve a high reliance on the rejection performance of optical filters, as well as bias drift induced by thermal and carrier effects. Additionally, high-order frequency multiplication imposes stringent demands on microwave packaging. It requires low-loss radio-frequency interfaces that can support higher frequency bands. Furthermore, an increase in the multiplication order is often accompanied by a reduction in optical sideband power, which may deteriorate the system's SNR and dynamic range. Looking forward, with the continuous advancement of photonic integration technology and optoelectronic packaging technology, more efficient high-order frequency multiplication architectures are anticipated to be realized while controlling system complexity. This will drive integrated microwave photonic radar toward higher frequency bands and superior performance.

B. Optical Up/Down-Conversion (OUDC) Architecture

Another category of microwave photonic radar chips generates an up-converted signal through heterodyne mixing between an OC modulated by an intermediate-frequency (IF) waveform and another OC with a distinct wavelength. In the receiver, optical down-conversion is implemented using the same wavelengths.

Figure 1 (d) depicts a typical schematic diagram of this architecture. In both the transmitter and the receiver, one arm of the MZM is driven by an RF clock signal with a frequency of f_{ck}. Owing to the high modulation voltage of this clock signal, a series of optical modulation sidebands are produced, thereby forming an optical frequency comb with a spacing of f_{ck} centered at the laser frequency. The frequencies of these sidebands can be represented as $f_0 \pm nf_{ck}$, where n = 1, 2, 3, 4, ⋯. In the transmitter, the other arm of the MZM is modulated by an IF signal with a frequency of f_{IF}. The two optical signals are combined at the output of the modulator and then fed into a PD, where optical beating conducts up-conversion. This process generates multiple RF signals at frequencies given by

$$f_{RF} = nf_{CK} \pm f_{IF} \quad (6)$$

These signals are subsequently filtered and amplified by the RF front-end before being transmitted. In the receiver, the echo signal at f_{RF} drives the other arm of the receiver MZM. Similarly, this signal mixes with the local optical frequency comb to achieve down-conversion, recovering the corresponding IF signal for subsequent acquisition and processing.

This architecture has been implemented on an SOI platform to realize an X-band radar system [38]. In this system, a 3.333 GHz clock generates a 9.9 GHz RF carrier, and a 40 MHz-bandwidth LFM signal centered at 100 MHz serves as the IF signal. The experimental results indicate that the system attains a theoretical range resolution of 3.75 m and effectively detects a wire-mesh cylindrical target moving at a velocity of 5 m/s from a distance of approximately 6 m.

To realize the integration of optical frequency comb generation, researchers have proposed a microwave photonic multifunctional system based on a silicon-nitride microcomb [39]. The core of this system is a chip-scale microcomb oscillator, which is formed by integrating a commercial InP distributed feedback laser with an Si_3N_4 microresonator having an intrinsic quality factor (Q) as high as 4.3×10^7 through self-injection locking. By utilizing this ultra-high-Q microcavity, the oscillator generates a coherent optical frequency comb with a repetition rate of approximately 35.3 GHz and a phase noise of -85 dBc/Hz at a 10 kHz offset. This microcomb oscillator not only functions as a low-noise microwave signal source but also offers a unified clock reference for the entire system after frequency division. Based on this, a microcomb-synchronized wireless joint sensing and communication system prototype was developed, successfully demonstrating high-resolution imaging and precise velocity measurement of targets in radar mode. It is noteworthy that this work provides a novel approach for integrated optical frequency comb generation in microwave photonic radar, although it has not yet integrated other key transceiver components, such as modulators and PDs. The validation of radar functionality was still carried out using a system prototype constructed from discrete optical and electronic components.

The advantages of this scheme are its frequency flexibility and intrinsic signal coherence. By adjusting the OC wavelength or the parameters of the optical frequency comb, multi-band radar signals can be generated within a relatively broad frequency range. Moreover, since all band signals are derived from the same optical frequency comb, they possess intrinsic phase coherence, which is conducive to coherent data fusion processing. Nevertheless, this approach also has notable limitations: the instantaneous bandwidth is restricted by the performance of the electrical waveform generator, and the power of individual comb lines after splitting is relatively low, which may have a negative impact on the system's dynamic range.

Reference [40] proposes an alternative method for radar waveform generation. Unlike architectures relying on electrical waveform generators and optical frequency combs, this method directly utilizes the inherent phase noise of free-running lasers. In this scheme, an RF noise waveform with a tunable center frequency is generated by heterodyne beating between a narrow-linewidth OC and a wide-linewidth, frequency-tunable optical LO coupled on-chip. At the receiver side, the echo signal is first modulated onto the OC via an MZM on the same chip, and then coupled with the optical LO in an on-chip 90° optical hybrid. The output signal is transmitted via optical fiber to the central unit, where a balanced photodetector configuration performs coherent detection to obtain the baseband signal. To alleviate the significant phase noise introduced by free-running lasers during down-conversion, a digital feed-forward noise reference technique is utilized. Experimental results indicate that reconfigurable operation can be achieved at 8 GHz and 33 GHz by adjusting the LO frequency. Ranging of simulated targets at distances of approximately 7.66 m and 12.24 m is accomplished with a range resolution of around 0.8 m.

III. Functionally Enhanced Microwave Photonic Radar Chips

Section II presents two fundamental architectures for microwave photonic radar chips, which have verified the feasibility of photonic integration technology in radar signal generation and processing, thus laying the foundation for the miniaturization of radar systems. Nevertheless, as application scenarios impose increasingly stringent requirements on radar performance, single-function fundamental architectures are no longer capable of meeting practical needs. This section focuses on recent advancements in functionally enhanced microwave photonic radar chips. Building on existing architectures, key technologies, such as multi-band fusion, multi-channel integration, and radar-lidar heterogeneous fusion, are introduced, which can substantially enhance the overall system performance.

A. Multi-Band Microwave Photonic Radar Chips

As discussed in Section II, the optical frequency comb-based OUDC architecture exhibits excellent frequency flexibility, which facilitates the realization of multi-band radar functionality. Microwave photonic radar chips based on this architecture can simultaneously generate signals in the S-band (3.4 GHz), C-band (6.9 GHz), X-band (10.4 GHz), and Ku-band (14.1 GHz), and has successfully conducted joint S-band and X-band detection experiments in a real maritime environment [41]. Reference [42] proposes a multi-band radar chip scheme based on an optical frequency comb. Different from the architecture described in [41], this chip utilizes a single modulator to generate the optical frequency comb signal, which is subsequently fed into the modulators in the transmitter and the receiver, respectively. This scheme also realizes simultaneous operation in the S, C, X, and Ku bands, with back-to-back radar system tests conducted in the S and X bands.

Meanwhile, significant progresses have also been made in multi-band radar systems based on integrated FMDP architectures. A multi-chirp-rate, multi-band ISAR system enabled by a "Multiple-in-One" integrated photonic chip is proposed [43]. By leveraging the low half-wave voltage characteristic of TFLN modulators, this system simultaneously generates four independent band signals spanning from 3.6 GHz to 16.0 GHz, utilizing only a single IF-LFM signal with a 0.4 GHz bandwidth with a large modulation index. Through coherent fusion processing, an equivalent bandwidth of 12.4 GHz is attained, resulting in a high range resolution of 1.26 cm. In [44], a dual-band microwave photonic radar chip based on an SOI platform is reported using the FMDP architecture. By adjusting the bias point of the MZM in the transmitter, this chip enables flexible switching of the operating frequency between the C-band and the Ku-band, demonstrating favorable reconfigurability.

B. Multi-Channel Microwave Photonic Radar Chips

Multi-channel radar, through the parallel processing of multiple signals, can effectively overcome the inherent limitations of traditional single-channel systems in resolution and information acquisition capabilities.

Figure 2(a) depicts an SOI microwave photonic radar chip with one transmitter and two receivers for joint range and azimuth detection [45]. It forms a cascaded structure consisting of a MZM followed by an asymmetrical dual-drive MZM (DDMZM). Photonic frequency doubling at the MZM generates a broadband linear frequency-modulated (LFM) signal. Meanwhile, the asymmetrical DDMZM utilizes its amplitude-frequency response to convert phase-modulated echoes into intensity modulation. This procedure results in two de-chirped signals with different frequencies. Target range is determined from the frequency of the de-chirped signals, and target azimuth is extracted from the their frequency difference.

Our group further implement the multi-channel architecture with synthetic bandwidth technology, fabricating a dual-channel photonic transceiver chip on the TFLN platform, as shown in Fig. 2(b). Each channel independently generates a frequency-doubled LFM signal. Through the coherent combination of the two signals, the bandwidth is further doubled, enabling a fourfold improvement in range resolution.

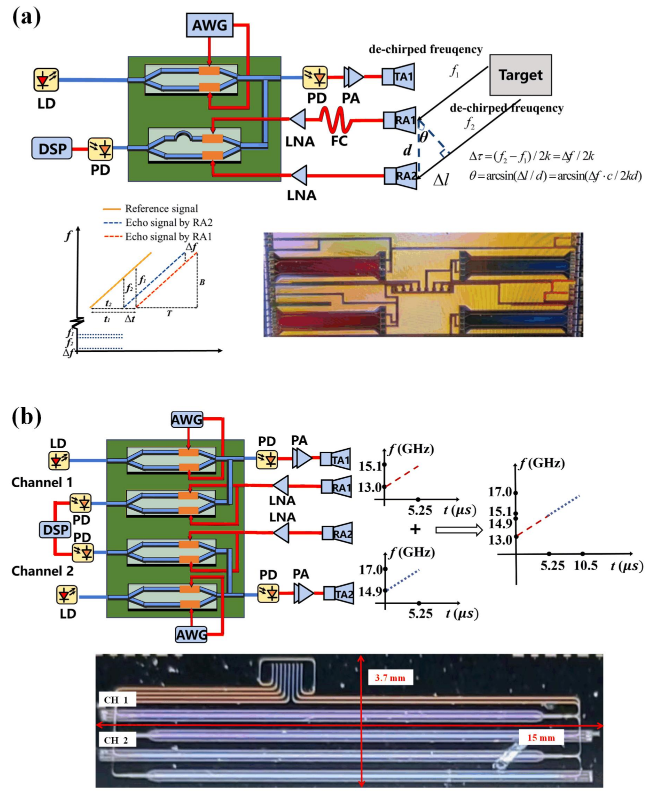

Fig. 2. Schematic diagram and chip photographs of (a) a microwave photonic radar chip scheme with one transmitter and two receivers [45], and (b) a synthetic-bandwidth microwave photonic radar chip.

C. Combined Radar & Lidar Chip

Radar systems offer all-weather operational capabilities, whereas lidar, despite providing higher angular resolution, remains susceptible to adverse weather conditions and atmospheric attenuation. Therefore, the two sensing methods exhibit intrinsic complementarity in their detection functionalities. Sharing a common optical architecture for microwave photonic radar and lidar not only effectively reduces system cost and structural complexity, but also enables in-depth photonic-level integration to support synchronous acquisition and coherent processing of radar and lidar data, thus achieving more precise and real-time scene reconstruction. To this end, an integrated radar-lidar chip fabricated on an SOI photonic chip is presented [46]. The chip adopts a shared architecture comprising an external laser source and digital processing units, wherein an on-chip optical splitter distributes the optical signal to the radar and lidar subsystems. The radar subsystem performs multi-band OUDC based on an optical frequency comb, which supports reconfigurable operation across the S, C, X, and Ku bands. Meanwhile, the lidar subsystem employs an MZM to load modulation waveforms for ranging and integrates a 90° optical hybrid mixer together with four PDs to conduct coherent detection, enabling the simultaneous acquisition of target range and velocity information.

III. Heterogeneously Integrated Microwave Photonic Radars

The microwave photonic radar chips mentioned above are mainly based on SOI or TFLN platforms. However, both platforms have inherent limitations: neither SOI nor TFLN supports on-chip laser integration, and the TFLN platform also faces challenges in integrating PDs. Consequently, to realize fully functional integrated microwave photonic radar chips, it is necessary to adopt heterogeneous integration technologies that enable the efficient coupling of active chips, such as InP-based lasers and PDs, with SOI or TFLN chips.

Spatial optical coupling, as a mature chip-to-chip optical interconnection solution, has been successfully demostrated in the development of a fully integrated hybrid microwave photonic receiver [47]. An InP laser chip is integrated with a monolithic SOI photonic circuit on the same substrate, resulting in a receiver module with a volume of merely 6 cm^3. This module integrates a laser source, two high-speed phase modulators, two micro-ring resonator-based tunable optical filters, and a PD array, which performs the de-chirped reception of radar echo signals from the S-band to the Ku-band.

Recently, our group has developed an integrated microwave photonic radar module based on optoelectronic-microwave heterogeneous integration. Through optical coupling and RF micro-assembly techniques, optical chips, including lasers, modulators, and PDs, along with microwave chips such as low-noise amplifiers, filters, and power dividers, are heterogeneously integrated into a single package with a size of 4.75 cm × 9.5 cm × 1.8 cm. This integration reduces system volume and weight by one order of magnitude, while successfully maintaining Ku-band radar functionality.

Conventional spatial optical coupling schemes would encounter intrinsic challenges, such as strict 3D alignment accuracy requirements, limited degrees of freedom, and relatively large packaging volumes. These limitations are particularly pronounced in heterogeneous integration scenarios involving multiple material platforms, diverse chip components, and high-channel-count arrays, thereby imposing inherent constraints on integration density and scalability. Photonic wire bonding (PWB) technology provides a highly flexible solution for hybrid integration. Based on two-photon polymerization lithography, PWB enables in-situ printing of 3D freeform polymer waveguides [48]. The geometric structure of these polymer waveguides can be tailored to match the mode-field profiles of chips fabricated from disparate materials, thereby achieving high-tolerance, low-loss chip-to-chip interconnection. To date, this technology has been successfully applied in multiple cutting-edge fields, including ultra-high-speed optical communications [49], high-performance hybrid integrated light sources [50], optical frequency combs [51], and optical neural networks [52]. Our group has successfully demonstrated the interconnection of three chips made of different materials, including InP lasers, TFLN modulators, and GaAs PDs, employing PWB technology, as depicted in Figure 3, and has accomplished the validation of Ku-band radar functionality [53]. PWB technology has demonstrated preliminary for commercial deployment. Its reliability has been substantiated by industrial qualification tests, including over 3000 hours of damp-heat testing at 85 ℃/85% relative humidity, as well as multiple temperature cycles switching between between -40 ℃ and +85 ℃ [49]. Concurrently, commercial entities such as Freedom Photonics have begun to offer prototyping and low-volume production services based on PWB [54]. Nevertheless, several critical challenges remain, including limited writing speed, which poses a bottleneck for high-throughput manufacturing; yield loss primarily attributable to process-induced defects; and the stringent requirement for uniformity in device facet quality.

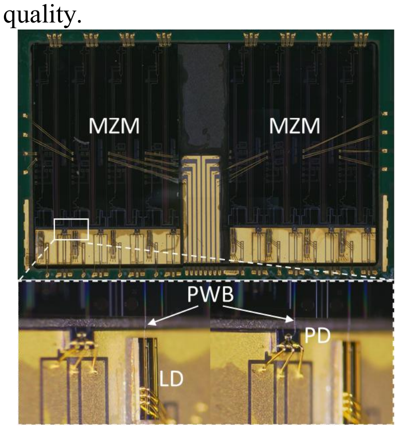

Fig. 3 Photograph of the integrated microwave photonic radar based on the PWB technology.

Furthermore, micro-transfer printing (μTP) technology, which employs an elastomeric stamp to transfer micro-scale devices from a source substrate to a target platform, offers a scalable manufacturing approach for multi-band integrated radar transceivers. For example, transferring an InP semiconductor optical amplifier onto an SOI circuit enables its gain to compensate silicon platform conversion losses [55]. Although the demonstration in [55] has not directly employ μTP for light source integration, this technology inherently possesses the capability to integrate a diverse range of active and passive optical devices. Currently in the pilot production stage, μTP exhibits a maturity level bridging research and

This article has been accepted for publication in Journal of Lightwave Technology. This is the author's version which has not been fully edited and content may change prior to final publication. Citation information: DOI 10.1109/JLT.2026.3713375

development with volume manufacturing. To facilitate its industrial adoption, several critical issues must be addressed. These include improving the yield of each fabrication step, while concurrently optimizing the performance and reliabillity of the transfer-printed devices. Furthermore, multi-coupon parallel printing must be developed to increase throughput, and wafer-level pitch and positional alignment issues must be resolved during the design phase [56].

TABLE. 1 Performance comparison of integrated microwave photonic radars

Architecture	Integration Platform	Integration Devices	Working Frequency (GHz)	Bandwidth (GHz)	Functionality				Ref.
					Distance resolution (cm)	Velocity resolution (m/s)	Image resolution (cm×cm)	Azimuth angle measurement (°)	
FMDP	SOI	MZM; PD	Ku(12-18)	6	2.7	—	NS	—	[36]
	TFLN	MZM	V(40-50)	10	1.5	0.067	1.5×1.06	—	[37]
	TFLN	MZM	S (3.6-4) C (7.2-8) X (10.8-12) Ku (14.4-16)	12.4 (equivalent bandwidth)	1.26	—	NS	—	[43]
	SOI	MZM; PD	C (6-8) Ku (12-16)	2 4	—	—	6.49×7.11 3.57×4.60	—	[44]
	SOI	MZM; PD	Ku (14-16)	2	NS	—	—	16.6	[45]
	InP; TFLN; GaAs	LD; MZM; PD	Ku (14-16)	2	6.9	—	—	—	[a][Under Review]
	InP; TFLN; GaAs	LD; MZM; PD	Ku (14-16)	2	7.2	—	—	—	[b][53]
OUDC	SOI	MZM	0.5-35 (8; 33)	0.2	80	NS	—	—	[40]
	SOI	MZM; PD	S (2.575) X (9.875)	0.02	750	NS	NS	—	[41]
	SOI	MZM; PD	S C X (9.7) Ku	0.1	150	—	—	—	[c][42]
	SOI	MZM; PD	S (3.4) C (6.9) X (10.4) Ku (14.1)	0.1	150	0.5	—	—	[46]

Note:
NS: function implemented but parameters not specified;
—: function not implemented;
[a]: the integration scheme based on optoelectronic-microwave heterogeneous integration;
[b]: the integration scheme based on PWB;
[c]: the architecture supports comb generation.

IV. DISCUSSIONS AND CONCLUSION

Table I provides a comparative overview of cutting-edge microwave photonic radar chips. Characterized by its structural simplicity, the FMDP architecture leverages electro-optic modulation to generate frequency-multiplied LFM signals via high-order sidebands. This makes it highly attractive for high-resolution imaging applications that demand fine range resolution. However, this architecture is inherently restricted to LFM waveforms for both transmission and reception, severely limiting signal format flexibility. Additionally, the necessity of an electrical baseband LFM signal at a specific frequency as the modulation input inevitably increases transmitter complexity and cost. In contrast, the OUDC architecture excels in multi-band flexibility and waveform diversity. By utilizing heterodyne mixing between two optical carriers derived from an optical frequency comb, it enables radar signal synthesis across multiple frequency bands with minimal constraints on waveform selection. Waveform reconfigurability can be readily achieved by simply substituting the IF signal with other waveform types. Nevertheless, the instantaneous bandwidth remains fundamentally limited by the performance of the electrical waveform generator, which may hinder its deployment in wideband applications. In terms of material platforms, SOI is the most widely adopted owing to its high maturity. Meanwhile, TFLN demonstrates distinct advantages in high-frequency applications, attributed to its superior electro-optic properties. Nevertheless, no single material platform can currently fulfills the combined demands of high-performance light source, high-speed modulation, and low-loss transmission.

Although significant progress has been made in the integration of microwave photonic radar, pursuing high integration levels still faces critical bottlenecks that hinder its transition from laboratory settings to practical applications..

Performance limitations constitute the primary constraints. The repeated conversion processes from RF to optical and then back to RF within integrated links result in substantial losses, directly impairing system sensitivity and limiting the dynamic range. Silicon-based modulators are characterized by relatively high half-wave voltages, and the free-carrier absorption effect further exacerbates optical power attenuation. The lack of mature on-chip optical amplification renders link compensation particularly challenging. Enhancing the dynamic range is also fraught with difficulties, as factors such as modulator nonlinearity, detector saturation, and laser noise impose significant restrictions on performance. Although balanced detection and linearization techniques can yield certain improvements, they result in increased system complexity and control difficulty. More crucially, in an integrated environment, the performance deficiencies of individual components are amplified through cascaded links, creating a "short-board effect", which contrasts sharply with the potential for independent optimization in discrete systems.

Integration challenges are equally formidable. Single-material platforms are insufficient to meet the performance demands of diverse functional devices. For instance, laser generation relies on the efficient light-emitting properties of InP; high-speed modulation depends on the excellent electro-optic coefficients of lithium niobate, lithium tantalate or barium titanate; and low-loss transmission requires the superior optical characteristics of silicon nitride. Therefore, heterogeneous integration has emerged as an indispensable approach. Advanced techniques such as PWB and μTP offer promising ways to harness the strengths of various material platforms, as discussed in Section III. Nevertheless, achieving high-performance heterogeneous integration still necessitates overcoming several fundamental challenges, including mode-field matching between waveguides of different materials, mismatches in lattice and thermal expansion coefficients, process compatibility, and high-yield manufacturing, all of which demand further in-depth investigation. Beyond overcoming technical bottlenecks, cultivating a mature industrial ecosystem is equally crucial for the large-scale adoption of optical heterogeneous integration. Unlike single-material platforms such as pure silicon photonics, optical heterogeneous integration is highly dependent on a deeply collaborative supply chain. This ecosystem must encompass not only suppliers of diverse base materials and core optical components, but also specialized foundries proficient in advanced assembly techniques such as PWB and μTP. Furthermore, it requires process equipment vendors and dedicated packaging and testing facilities tailored to the unique requirements of heterogeneously integrated chips. On this foundation, the widespread adoption of standardized design kits and unified optical interface protocols across the supply chain is crucial for accelerating development cycles and reducing manufacturing costs.

Packaging complexity constitutes a significant impediment. Microwave photonic radar chips generally contain at least two sets of modulators and detectors. This multi-channel configuration necessitates rigorous high-frequency broadband packaging standards to ensure precise impedance matching, maintain signal integrity, and effectively suppress inter-channel crosstalk. Meanwhile, thermal management issues arising from high-density integration cannot be overlooked. The temperature of the device affects bias stability, and thermal crosstalk can degrade the performance of adjacent components, rendering photonic-electronic-thermal co-design critical.

Additionally, functionality limitation represents another significant constraint in the ongoing advancement of microwave photonic radar chips. Although advanced functionalities, such as low-phase-noise OEOs for generating pure local oscillator signals, optical true time delay lines for squint-free broadband beam scanning, and optical ADCs capable of surmounting electronic sampling bottlenecks, have been individually demonstrated in an integrated form, their monolithic integration into a radar-specific chip remains a substantial challenge. This challenge arises from two fundamental issues. First, the performance of these components is still in a nascent stage, with many existing only as proof-of-concept demonstrations. Second, their integration introduces substantial architectural and control complexity, a problem exacerbated by the lack of mature fabrication processes capable of combining these components without compromising overall system performance.

In summary, the development of microwave photonic radar chips will persist in the direction of high-density integration and functional convergence. At the system architecture level, chips will progress towards multi-functionality, facilitating advanced applications such as integrated sensing and communication, cognitive radar, and lidar/radar fusion. At the functional component level, it is imperative to achieve comprehensive integration of OBFNs, OEOs, optical ADCs, and even photonic computing units to significantly improve system performance. At the physical implementation level, ongoing breakthroughs in device performance, heterogeneous integration of optoelectronic materials, and three-dimensional heterogeneous packaging technologies will be pivotal in achieving substantial performance improvements. Only by systematically addressing these technological challenges can microwave photonic radar chips transition from laboratory settings to practical applications, thereby realizing their unique and indispensable value in autonomous driving, low-earth-orbit satellites, portable detection, and next-generation wireless technologies.

REFERENCES

[1] J. Capmany and D. Novak, “Microwave photonics combines two worlds,” *Nature Photon.*, vol. 1, no. 6, pp. 319–330, Jun. 2007.

[2] J. Yao, “Microwave photonics,” *J. Lightw. Technol.*, vol. 27, no. 3, pp. 314–335, Feb. 2009.

[3] S. Pan and Y. Zhang, “Microwave photonic radars,” *J. Lightw. Technol.*, vol. 38, no. 19, pp. 5450–5484, Oct. 2020.

[4] P. Ghelfi *et al.*, “A fully photonics-based coherent radar system,” *Nature*, vol. 507, no. 7492, pp. 341–345, Mar. 2014.

[5] G. Serafino *et al.*, “Toward a new generation of radar systems based on microwave photonic technologies,” *J. Lightw. Technol.*, vol. 37, no. 2, pp. 643–650, Jan. 2019.

[6] F. Zhang *et al.*, "Photonics-based broadband radar for high-resolution and real-time inverse synthetic aperture imaging," *Opt. Express*, vol. 25, no. 14, pp. 16274–16281, Jul. 2017.

[7] R. Li *et al.*, "Demonstration of a microwave photonic synthetic aperture radar based on photonic-assisted signal generation and stretch processing," *Opt. Express*, vol. 25, no. 13, pp. 14334–14340, Jun. 2017.

[8] S. Zhang, W. Zou, N. Qian, and J. Chen, "Enlarged range and filter-tuned reception in photonic time-stretched microwave radar," *IEEE Photon. Technol. Lett.*, vol. 30, no. 11, pp. 1028–1031, Jun. 2018.

[9] S. Peng *et al.*, "High-resolution W-band ISAR imaging system utilizing a logic-operation-based photonic digital-to-analog converter," *Opt. Express*, vol. 26, no. 2, pp. 1978–1987, Jan. 2018.

[10] X. Ye, F. Zhang, Y. Yang, and S. Pan, "Photonics-based radar with balanced I/Q de-chirping for interference-suppressed high-resolution detection and imaging," *Photon. Res.*, vol. 7, no. 3, pp. 265–272, Mar. 2019.

[11] W. Zou, H. Zhang, X. Long, S. Zhang, Y. Cui, and J. Chen, "All-optical central-frequency-programmable and bandwidth-tailorable radar," *Sci. Rep.*, vol. 6, Art. no. 19786, Jan. 2016.

[12] X. Wang, F. Cao, C. Ma, Y. Yang, F. Zhang, and S. Pan, "Dual-band coherent microwave photonic radar using linear frequency modulated signals with arbitrary chirp rates," *IEEE J. Sel. Top. Quantum Electron.*, vol. 29, no. 6, pp. 1–9, Nov./Dec. 2023.

[13] X. Xiao, S. Li, S. Peng, X. Xue, X. Zheng, and B. Zhou, "Microwave photonic wideband distributed coherent aperture radar with high robustness to time synchronization error," *J. Lightw. Technol.*, vol. 39, no. 2, pp. 347–356, Jan. 2021.

[14] F. Zhang, G. Sun, Y. Zhou, B. Gao, and S. Pan, "Towards high-resolution imaging with photonics-based time division multiplexing MIMO radar," *IEEE J. Sel. Top. Quantum Electron.*, vol. 28, no. 5, pp. 1–10, Sept./Oct. 2022.

[15] D. Zhu and S. Pan, "Broadband cognitive radio enabled by photonics," *J. Lightw. Technol.*, vol. 38, no. 12, pp. 3076–3088, Jun. 2020.

[16] L. Wang, X. Wang, and S. Pan, "Microwave photonics empowered integrated sensing and communication for 6G," *IEEE Trans. Microw. Theory Techn.*, vol. 73, no. 8, pp. 5295–5315, Aug. 2025.

[17] J. Tang *et al.*, "Integrated optoelectronic oscillator," *Opt. Express*, vol. 26, no. 9, pp. 12257–12265, Apr. 2018.

[18] R. Ma *et al.*, "Ka-band thin film lithium niobate photonic integrated optoelectronic oscillator," *Photon. Res.*, vol. 12, no. 6, pp. 1283–1293, Jun. 2024.

[19] W. Zhang and J. Yao, "Silicon photonic integrated optoelectronic oscillator for frequency-tunable microwave generation," *J. Lightw. Technol.*, vol. 36, no. 19, pp. 4655–4663, Oct. 2018.

[20] P. Do, C. Alonso-Ramos, X. Le Roux, I. Ledoux, B. Journet, and E. Cassan, "Wideband tunable microwave signal generation in a silicon-micro-ring-based optoelectronic oscillator," *Sci. Rep.*, vol. 10, Art. no. 6982, Apr. 2020.

[21] Z. Han *et al.*, "Integrated ultra-wideband tunable Fourier domain mode-locked optoelectronic oscillator," *Laser Photon. Rev.*, vol. 19, no. 11, Art. no. 2402094, Nov. 2025.

[22] X. Hong, Y. Cheng, B. Wang, and W. Zhang, "On-chip photonic generation of tunable wideband phase-coded linearly-chirped microwave waveforms," *J. Lightw. Technol.*, vol. 41, no. 19, pp. 6199–6207, Oct. 2023.

[23] L. Wang *et al.*, "Photonic generation of multi-format radar waveforms based on an integrated silicon IQ modulator," *IEEE J. Sel. Top. Quantum Electron.*, vol. 28, no. 5, Art. no. 6000207, Sept./Oct. 2022.

[24] D. Drayss *et al.*, "Optical arbitrary waveform generation (OAWG) using actively phase-stabilized spectral stitching," *Light Sci. Appl.*, vol. 14, Art. no. 353, Sept. 2025.

[25] S. Shi *et al.*, "Integrated optical tunable delay line and microwave photonic beamforming chip: a review," *Laser Photon. Rev.*, vol. 19, no. 7, Art. no. 2400663, Jul. 2025.

[26] Y. Qin *et al.*, "Broadband lithium niobate integrated microwave photonic beamforming chip," *Laser Photon. Rev.*, vol. 19, no. 18, Art. no. 2500219, May 2025.

[27] C. Tsokos *et al.*, "True time delay optical beamforming network based on hybrid InP-silicon nitride integration," *J. Lightw. Technol.*, vol. 39, no. 18, pp. 5845–5854, Sept. 2021.

[28] R. Qin *et al.*, "Towards direct sampling of ultra-broadband microwave signals: a review of integrated photonic analog-to-digital converter technologies," *J. Lightw. Technol.*, vol. 43, no. 21, pp. 9793–9811, Nov. 2025.

[29] Y. Song *et al.*, "Integrated electro-optic digital-to-analogue link for efficient computing and arbitrary waveform generation," *Nature Photon.*, vol. 19, pp. 1107–1115, Aug. 2025.

[30] Y. Tao, F. Yang, Z. Tao, L. Chang, H. Shu, and M. Jin, "Fully on-chip microwave photonic instantaneous frequency measurement system," *Laser Photon. Rev.*, vol. 16, no. 9, Art. no. 2200158, Sept. 2022.

[31] L. Wang *et al.*, "Integrated ultra-wideband dynamic microwave frequency identification system in lithium niobate on insulator," *Laser Photon. Rev.*, vol. 18, no. 10, Art. no. 2400332, Oct. 2024.

[32] A. Ivanov, O. Morozov, A. Sakhabutdinov, A. Kuznetsov, and I. Nureev, "Photonic-assisted receivers for instantaneous microwave frequency measurement based on discriminators of resonance type," *Photonics*, vol. 9, no. 10, Art. no. 754, Oct. 2022.

[33] K. Singh, S. Preußler, A. Misra, L. Zhou, and T. Schneider, "Photonic microwave frequency measurement with high accuracy and sub-MHz resolution," *J. Lightw. Technol.*, vol. 40, no. 9, pp. 2748–2753, May 2022.

[34] M. Zong *et al.*, "Unambiguous DFS measurement system based on an integrated photonic chip with wavelength-selective modulation," *J. Lightw. Technol.*, vol. 44, no. 10, pp. 3923–3930, May 2026.

[35] Y. Zheng *et al.*, "Integrated microwave photonics multi-parameter measurement system," *Laser Photon. Rev.*, vol. 19, no. 14, Art. no. 2500013, Mar. 2025.

[36] S. Li *et al.*, "Chip-based microwave-photonic radar for high-resolution imaging," *Laser Photon. Rev.*, vol. 14, no. 10, Art. no. 1900239, Oct. 2020.

[37] S. Zhu *et al.*, "Integrated lithium niobate photonic millimetre-wave radar," *Nature Photon.*, vol. 19, no. 2, pp. 204–211, Feb. 2025.

[38] F. Scotti *et al.*, "Indoor field-trial in X band of a photonics-based multiband radar on a packaged silicon chip," in *Proc. IEEE Int. Topical Meeting Microw. Photon. (MWP)*, Pisa, Italy, 2021, pp. 1–4, Nov. 2021.

[39] X. Zhang *et al.*, "Microcomb-synchronized optoelectronics," *Nature Electron.*, vol. 8, no. 4, pp. 322–330, Apr. 2025.

[40] D. Onori and J. Azaña, "A broadly tunable noise radar transceiver on a silicon photonic chip," in *Proc. Opt. Fiber Commun. Conf. (OFC)*, San Diego, CA, USA, 2020, paper M4I.3, Mar. 2020.

[41] G. Serafino *et al.*, "Maritime field trial of a dual-band silicon integrated photonics-based radar," *IEEE J. Sel. Top. Quantum Electron.*, vol. 28, no. 5, pp. 1–10, Sept./Oct. 2022.

[42] F. Falconi, F. Scotti, C. Porzi, A. Das Barman, P. Ghelfi, and A. Bogoni, "Multiband radar based on integrated photonics," in *Proc. IEEE Int. Conf. Microw. Millim. Wave Technol. (ICMMT)*, Nanjing, China, 2021, pp. 1–3, May 2021.

[43] N. Zhong *et al.*, "Multiple-in-one photonic integrated transceiver for multi-chirp-rate & multi-band ISAR system and coherent fusion processing," *J. Lightw. Technol.*, vol. 42, no. 21, pp. 7434–7442, Nov. 2024.

[44] W. Ma, R. Wang, J. Liu, and W. Li, "High-performance integrated microwave photonic transceiver for dual-band synthetic aperture radar," *J. Lightw. Technol.*, vol. 42, no. 21, pp. 7482–7490, Nov. 2024.

[45] D. Yuan *et al.*, "Silicon-photonic-chip-based microwave photonic radar for simultaneous range and azimuth measurement," in *Proc. SPIE 14000, Fifth Int. Comput. Imag. Conf.*, 2025, Art. no. 140001C.

[46] F. Falconi *et al.*, "A combined radar & lidar system based on integrated photonics in silicon-on-insulator," *J. Lightw. Technol.*, vol. 39, no. 1, pp. 17–23, Jan. 2021.

[47] J. Li, S. Yang, H. Chen, X. Wang, M. Chen, and W. Zou, "Fully integrated hybrid microwave photonic receiver," *Photon. Res.*, vol. 10, no. 6, pp. 1472–1483, Jun. 2022.

[48] M. Billah *et al.*, "Hybrid integration of silicon photonics circuits and InP lasers by photonic wire bonding," *Optica*, vol. 5, no. 7, pp. 876–883, Jul. 2018.

[49] M. Blaicher *et al.*, "Hybrid multi-chip assembly of optical communication engines by in situ 3D nano-lithography," *Light Sci. Appl.*, vol. 9, Art. no. 71, Apr. 2020.

[50] C. Franken *et al.*, "High-power and narrow-linewidth laser on thin-film lithium niobate enabled by photonic wire bonding," *APL Photonics*, vol. 10, no. 2, Art. no. 026107, Feb. 2025.

[51] A. Takabayashi *et al.*, "Microresonator photonic wire bond integration for Kerr-microcomb generation," *Sci. Rep.*, vol. 14, Art. no. 27593, Nov. 2024.

[52] Y. Ma *et al.*, "Photonic convolution accelerator based on a hybrid integrated multi-wavelength laser array by photonic wire bonding for

real-time image classification," *Opt. Lett.*, vol. 49, no. 10, pp. 2629–2632, May 2024.

[53] M. Zong et al., "Hybrid-Integrated Microwave Photonic Radar Module via Photonic Wire Bonding," in *2026 Conference on Lasers and Electro-Optics/Pacific Rim (CLEO-PR)*, Aug. 2026.

[54] V. Rosborough *et al.*, "Photonic wire bonding via two-photon polymerization laser lithography for hybrid integration," in *Proc. SPIE 12424, Integrated Optics: Devices, Materials, and Technologies XXVII*, 2023, Art. no. 124240Q, pp. 147–151, Mar. 2023.

[55] F. Camponeschi *et al.*, "Heterogeneously integrated multi-band radar transceiver based on micro-transfer-printing," in *Proc. IEEE Int. Topical Meeting Microw. Photon. (MWP)*, 2024, pp. 1–4, Jun. 2024.

[56] Y. Chen *et al.*, "Micro-transfer printing on silicon photonics: tutorial, recent progress and outlook," *J. Lightw. Technol.*, early access, May 2026.

Simin Li received the B.S. and Ph.D. degrees from Nanjing University, Nanjing, China, in 2009 and 2014, respectively. She is currently an Associate Professor at the National Key Laboratory of Microwave Photonics, Nanjing University of Aeronautics and Astronautics, Nanjing, China.

Her research interests include integrated microwave photonic devices and systems.

Mengya Zong received the B.E. degree from Huaibei Normal University, Huaibei, China, in 2020 and M.E. degree from Beijing University of Technology, Beijing, China, in 2023, where she is currently pursuing the Ph.D. degree at Nanjing University of Aeronautics and Astronautics, Nanjing, China.

Her research interests include integrated microwave photonics.

Yu Zhang received the B.S. degree in electronic science and technology from the Nanjing University of Aeronautics and Astronautics, Nanjing, China, in 2025, where she is currently pursuing the Ph.D. degree.

Her research interests include integrated microwave photonics.

Dezhe Yuan received the B.E. degree from Sichuan Agricultural University, Ya'an, China, in 2023. He is currently pursuing the M.E. degree at Nanjing University of Aeronautics and Astronautics, Nanjing, China. His research interests include integrated microwave photonics.

Ming Li received the B.E. degree from Huaiyin Institute of Technology, Huaian, China, in 2019 and M.E. degree from Nanjing University of Aeronautics and Astronautics, Nanjing, China, in 2025. He is currently engaged in optical transceiver development at Jiangsu Allray Optoelectronics Co., Ltd.

JiJun He received the B.S. degree in optical information science and technology from the University of Science and Technology of China, Hefei, China, in 2013, and the Ph.D. degree in optical engineering from The Hong Kong Polytechnic University, Hong Kong, in 2019. He was a Postdoctoral Scientist with the Laboratory of Photonics and Quantum Measurements, École Polytechnique Fédérale de Lausanne (EPFL), Lausanne, Switzerland, from 2019 to 2021. He is currently a Professor with the College of Electronic and Information Engineering, Nanjing University of Aeronautics and Astronautics (NUAA), Nanjing, China, and serves as the Deputy Director of the Device Academic Division at the National Key Laboratory of Microwave Photonics. He has authored or co-authored over 50 papers in prestigious journals including Nature, Science, Nature Photonics, and Nature Communications.

Shilong Pan is currently a professor of Nanjing University of Aeronautics and Astronautics, China. His research has focused on microwave photonics, which includes optical generation and processing of microwave signals, analog photonic links, photonic microwave measurement, and integrated microwave photonics. He has authored or co-authored over 350 papers in peer-reviewed journals.

Prof. Pan is currently the executive editor of PhotoniX Synergy and an associate editor of Journal of Lightwave Technology, and is the vice chair of IEEE MTT-22 Microwave Photonics. He has also served as a Chair of a number of international conferences, symposia, and workshops, including the TPC Chair of IEEE ICOCN 2015, the TPC chair of IEEE MWP 2023, a TPC Co-chair of IEEE MWP 2017, and a General Co-chair of IEEE MWP 2021 and 2025.

Prof. Pan is a Fellow of IEEE, Optica, and SPIE. He was selected as an IEEE Photonics Society Distinguished Lecturer in 2019 and an IEEE MTT-S Distinguished Microwave Lecturer in 2022, and was a recipient of IEEE MTT-S Outstanding Young Engineer Award in 2021.