Supplementary Information for:

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Plasmonic IQ Modulators with Attojoule per Bit Electrical Energy Consumption

Supplementary Table 1: State-of-the-art IQ modulators

Technology	Fiber-to-fiber loss [dB]	Device loss [dB]	$U_\pi L$ [Vmm]	Active Length [mm]	Line rate [Gbit/s]	EO Bandwidth	Reference
$LiNbO_3$	~10	-	10-100	10-100	600	~40 GHz	[1,2]
GaAs	18	< 8 dB	90	30	150	~30 GHz	[3]
Si	~15	6.8 dB	30	4.5	350	~30 GHz	[4]
InP	9	~2 dB	~5	~3.6	448	~70 GHz	[5,6]
SOH	17.5*	8.5 dB	1	0.6	400	~40 GHz	[7]
Plasmonic-Organic Hybrid	19.2*	11.2	0.13	0.015	400	>500 GHz [8]	This work

* fiber-to-fiber losses can be reduced to <10 dB when relying on a dedicated fabrication process

Supplementary Table 2 Summary of investigated devices including fiber-to-fiber and on-chip losses.

Device	L_{active} [µm]	w_{slot} [nm]	On-chip loss [dB]	Photonic-plasmonic converter loss [dB]	Loss plasmonic section [dB]	Fiber-to-chip coupling loss [dB per coupler]	Fiber-to-fiber loss [dB]
IQ1621	15	130	~11.2	~1.7	~7.8	~4	19.2
IQ2622	20	130	~14.5	~1.7	~11.1	~4	22.5
IQ3626	20	130	~13.7	~1.7	~10.3	~4	21.7

Supplementary Table 3 Measurements of Figure 2

Modulation	Device	$U_{meas50\Omega,pp}$ [V]	E_{bit} † [fJ bit^{-1}]	BER	BER without el. equalizer	P_{opt} [dBm]	$U_{IQ,pk}$ [V]
50 GBd QPSK (100 Gbit s^{-1})	IQ1	~2.0	10.2	6.86×10^{-8}*	3.3×10^{-4}	20	~2.0
	IQ2	1.92	12.4	4.96×10^{-6}┼	5.9×10^{-4}┼	15	1.92
	IQ3	1.92	12.4	8.25×10^{-23}*	1.9×10^{-9}*	18	1.92
50 GBd 16QAM (200 Gbit s^{-1})	IQ1	2.95	6.2	1.9×10^{-4}┼	6.6×10^{-3}┼	20	2.95
	IQ3	1.99	3.7	3.1×10^{-4}	6.8×10^{-3}	18	1.99
100 GBd QPSK (200 Gbit s^{-1})	IQ1	2.23	12.7	6.63×10^{-9}*	1.6×10^{-6}	18	2.23
	IQ2	3.45	40.0	1.26×10^{-6}*	5.2×10^{-5}	19	3.45
	IQ3	1.77	10.5	2.97×10^{-7}*	6.5×10^{-5}	18	1.77
100 GBd 16QAM (400 Gbit s^{-1})	IQ1	2.75	5.36	1.37×10^{-2}	6.3×10^{-2}	20	2.75
	IQ2	2.67	6.64	1.48×10^{-2}	6.4×10^{-2}	15	2.67
	IQ3	1.48	2.04	2.36×10^{-2}	4.5×10^{-2}	20	1.48

†Device capacitance of IQ1: 2.55 fF, for IQ2 and IQ3: 3.36 fF *BER estimated from SNR, no/not enough errors counted for statistical relevant measured BER.[9] ┼Measurement performed with uncalibrated transmitter, BER estimated from SNR.

Supplementary Table 4 Electrical energy consumption per bit at different symbol rates / modulation formats. All measurements performed with IQ3.

Modulation	$U_{meas50\Omega,pp}$	E_{bit}	**BER**	$U_{DAC,pp}$	$U_{IQ,pk}$	**Attenuator**
25 GBd QPSK (50 Gbit s^{-1})	145 mV	0.07 fJ bit^{-1}	2.0×10^{-3}	350 mV	145 mV	6 dB
	187 mV	0.12 fJ bit^{-1}	1.66×10^{-5}*	450 mV	187 mV	6 dB
50 GBd QPSK (100 Gbit s^{-1})	326 mV	0.36 fJ bit^{-1}	2.0×10^{-4}	350 mV	326 mV	0 dB
50 GBd 16 QAM (200 Gbit s^{-1})	567 mV	0.30 fJ bit^{-1}	2.0×10^{-2}	650 mV	567 mV	0 dB
100 GBd QPSK (200 Gbit s^{-1})	426 mV	0.61 fJ bit^{-1}	1.4×10^{-3}	650 mV	426 mV	0 dB
100 GBd 16QAM (400 Gbit s^{-1})	1.48 V	2.04 fJ bit^{-1}	2.36×10^{-2}	650 mV	1.48 V	RF Amplifier

* BER estimated from SNR, no/not enough errors counted for statistical relevant measured BER.[9]

Supplementary Table 5: Operation at elevated temperatures. Measurement parameters of measurements M1-M5 shown in Figure 3. All measurements at 100 Gbit s^{-1} (50GBd QPSK).

	Temp	Time at temp	Operating time	BER	EVM
	~22.5	>8h	7h	8.4×10^{-06}*┼	22.5 %┼
M1	42 °C	20 min	7.8 h	3.9×10^{-8}*	18.4 %
M2	65 °C	25 min	8.7 h	6.38×10^{-7}*	20.1 %
M3	65 °C	70 min	9.4 h	9.24×10^{-6}*	22.6 %
M4	75 °C	20 min	10 h	7.08×10^{-7}*	20.4 %
M5	75 °C	80 min	11 h	2.31×10^{-6}*	21.2 %

* BER estimated from SNR, no/not enough errors counted for statistical relevant measured BER.[9] ┼Measurement performed with uncalibrated transmitter.

Supplementary References

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