State-of-the-art high bit rate VCSELs for SR OIs

	2010	2014	2013	2012	2012	2014	2014
Affiliation	CHT[1]	UIUC[2]	TUB[3]	CHT[4]	TUB[5]	TUB[6]	**TUB[6]**
Wavelength	850	850	850	850	980	980	**980**
Temp (°C)	RT	20	RT	85	25	25	**85**
Bit Rate (Gbit/s)	40	40	**40**	40	35	42	**38**
Distance (m)[b]	BTB	BTB	BTB	BTB	BTB	BTB	**BTB**
EDR (fJ/bit)	~600[e]	~435[c]	**158**	~594[d]	287	339	**203**
HBR[a] (fJ/bit)	450	~395[c]	**108**	~489[d]	233	296	**177**
Aperture (μm)	7	4	4	7	4	~4.0	**~4.0**
~***J*** (kA/cm^2)	20.8	51.7[c]	23.8	24.7	31.8	43.8	**28.6**

[a] Heat-to-bit rate ratio (HBR) may equivalently be given in units of mW/Tbps

[b] Back-to-back (BTB) is ~2 to 3 m of MMF as required in our high frequency test set-up

[c] estimated (6.5 mA at 2.7 V with L_{out}~1.75 mW); [d] estimated (9.5 mA at 2.5 V with L_{out}~4.2mW);

[e] estimated (8.0 mA at 3.0 V with L_{out}~6.0 mW)

[1] P. Westbergh *et al.*, Electronics Letters, 46 (14), (08 July 2010).

[2] F. Tan, M.-K. Wu, M. Liu, *et al.*, IEEE Photonics Technology Letters, 26 (3), pp. 289-292 (01 February 2014)

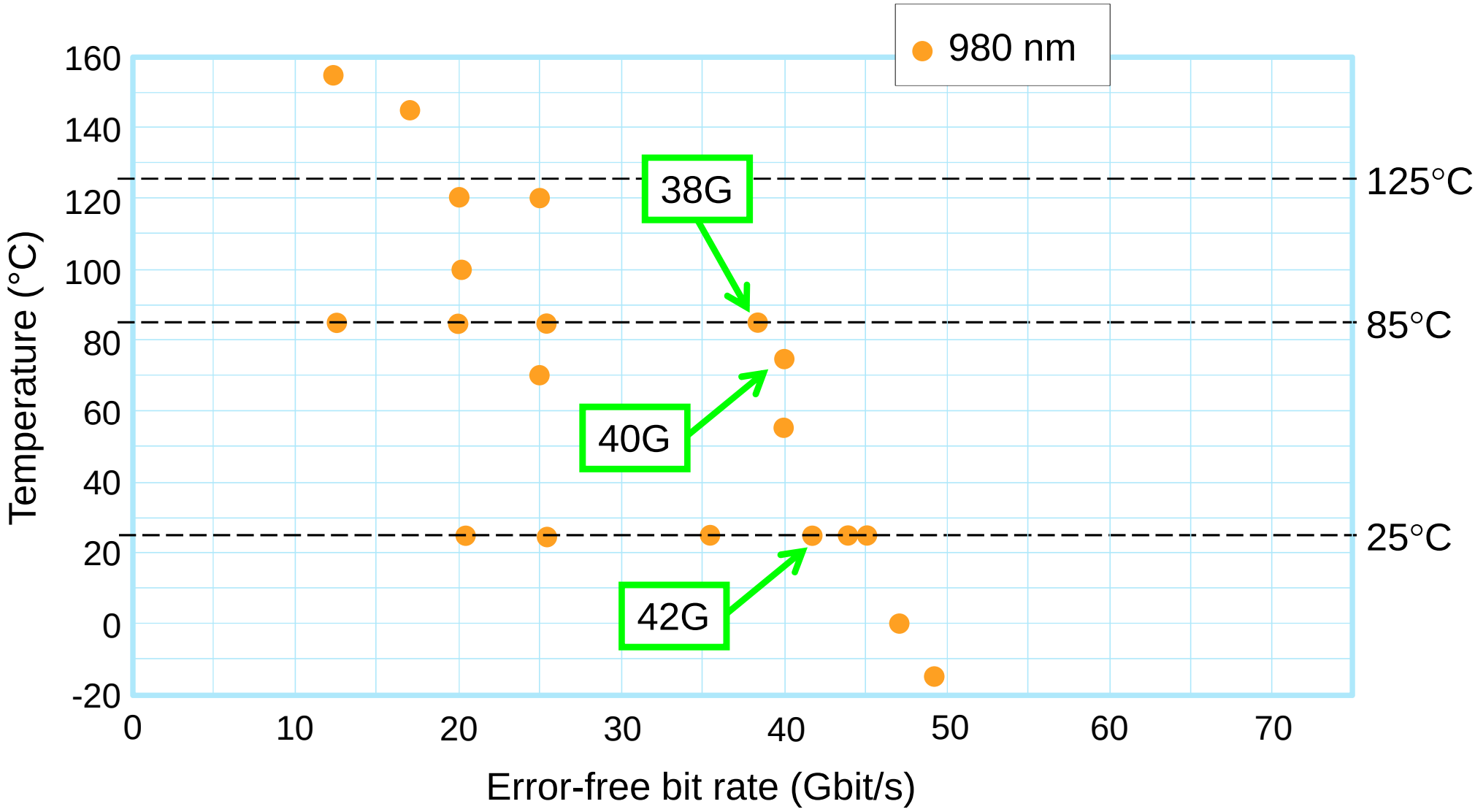
[3] P. Wolf, P. Moser, . . ., D. Bimberg, Electronics Letters, 49 (10), pp. 666-667 (09 May 2013).

[4] P. Westbergh *et al.*, IEEE Photonics Technology Letters, 25 (8), pp. 768-771 (15 April 2013).

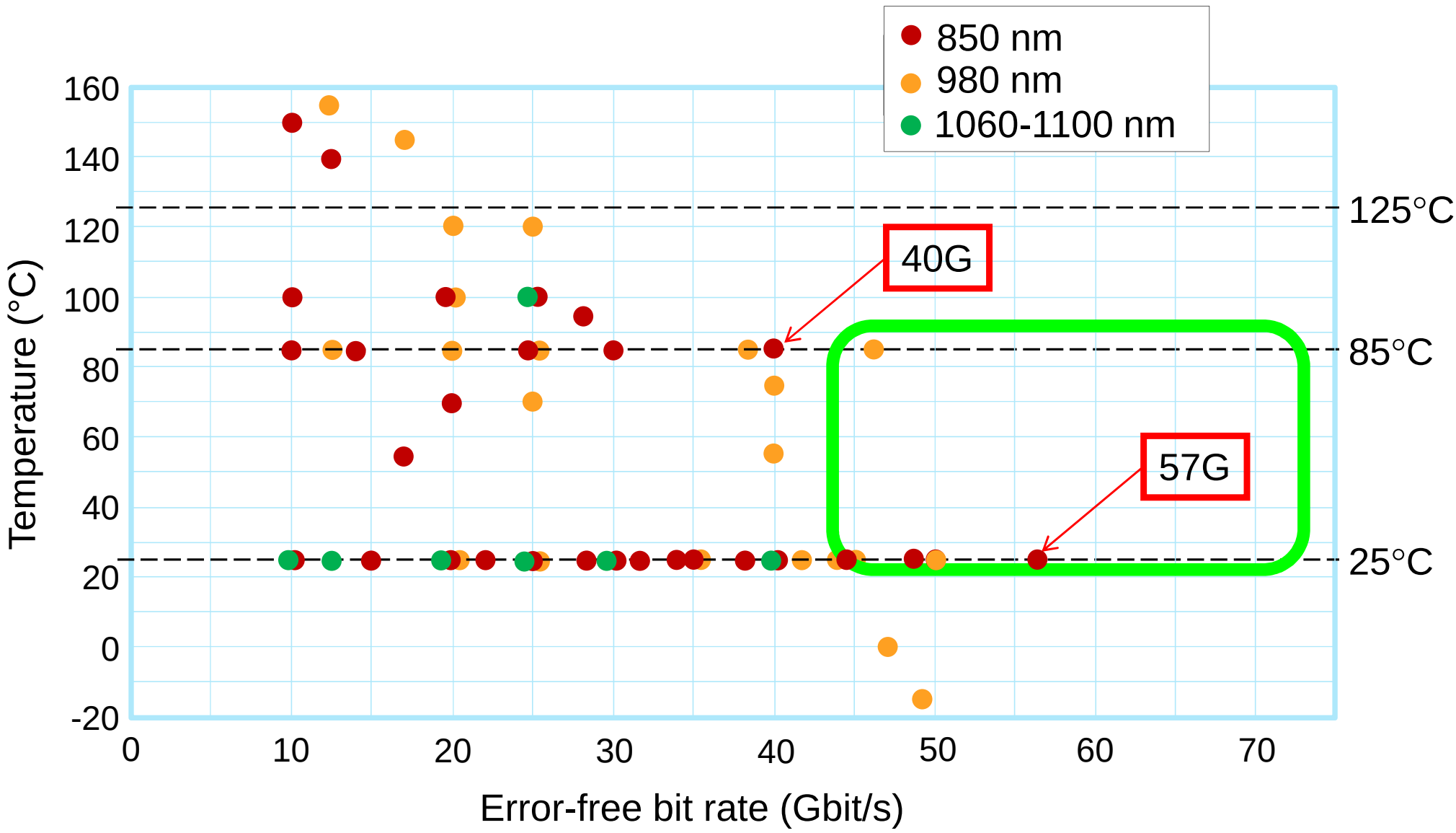
[5] P. Moser, . . ., D. Bimberg, Applied Physics Letters, 100, 081103 (2012).

[6] H. Li, . . ., D. Bimberg, unpublished.

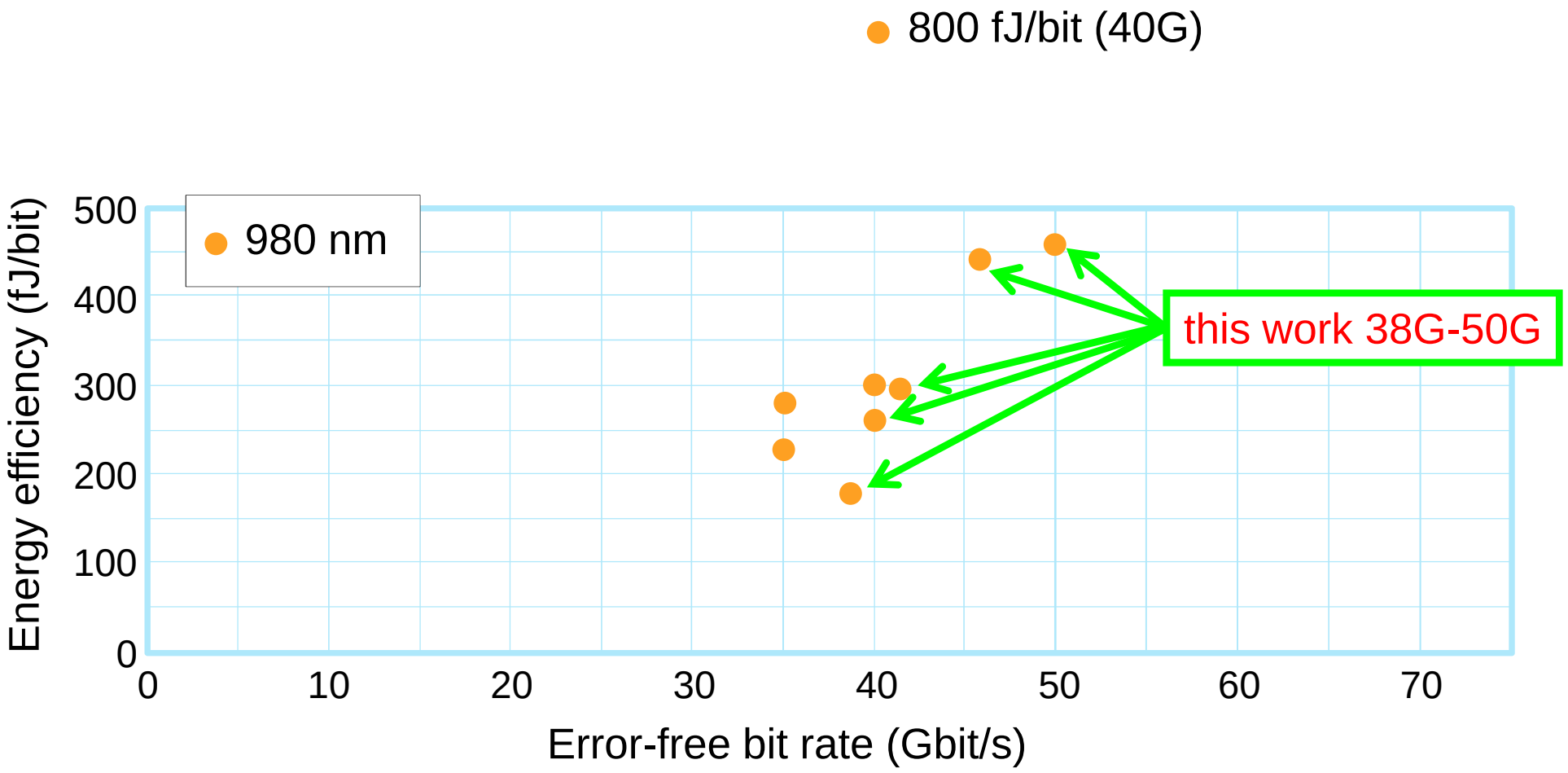
980 nm VCSELs to date



VCSELs to date

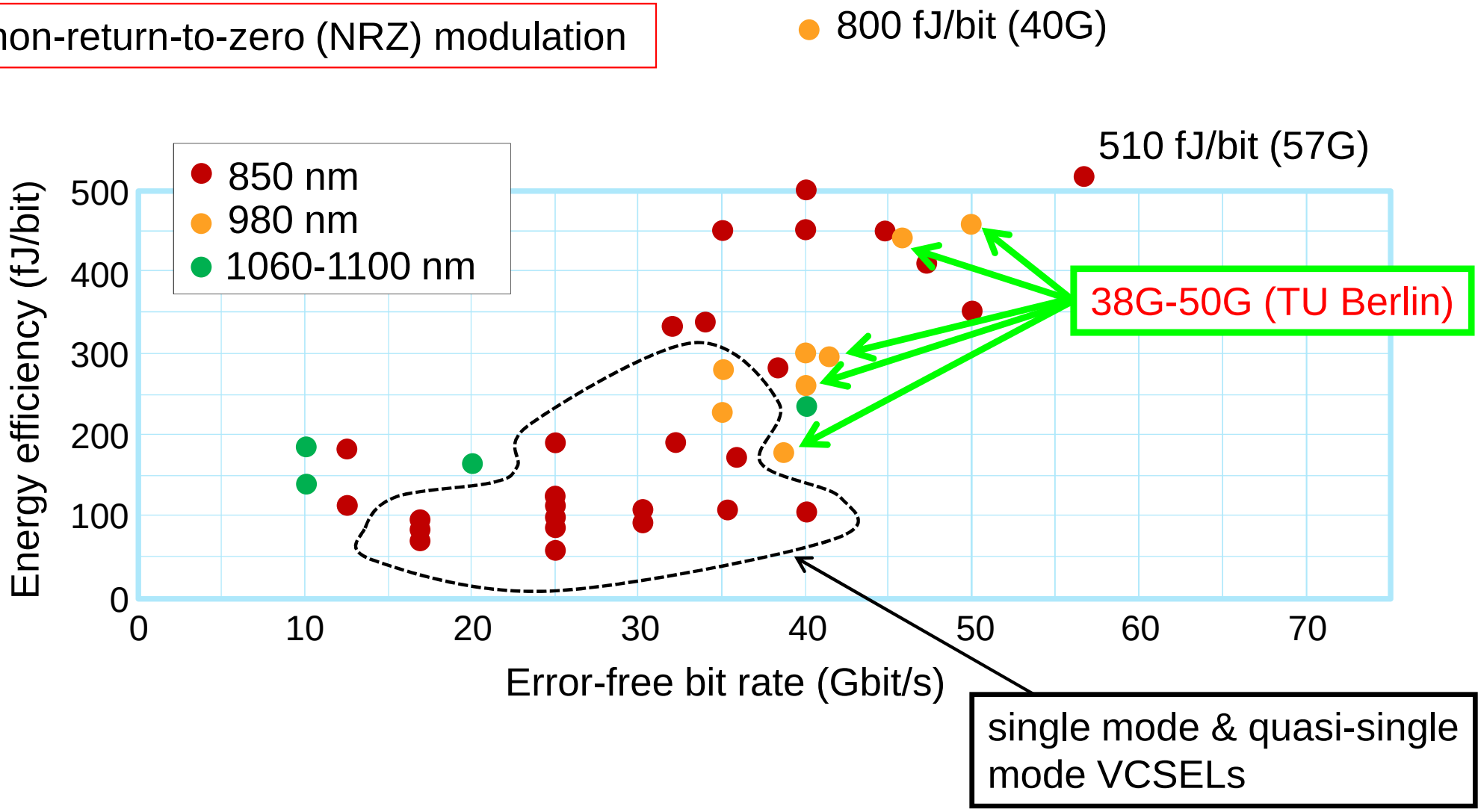


Energy-efficient 980 nm VCSELs



VCSEL energy efficiency vs. bit rate

non-return-to-zero (NRZ) modulation



”error-free” (typically BER <1E-12) back-to-back or across MMF

Summary and conclusion

850 nm VCSELs

- 56 fJ/bit at 25°C (BTB)
- 25 Gbit/s at 25°C (BTB)
- simultaneous high bit rate and energy efficiency

- 25 Gbit/s at 100 fJ/bit at 25°C (1 km)
- 30 Gbit/s at 85 fJ/bit at 25°C (500 m)
- 40 Gbit/s at 119 fJ/bit at 25°C (50 m)
- simultaneous high bit rate, energy efficiency, & record MMF distance

Our single-mode (and quasi-SM) VCSELs . . .

- are more energy-efficient than similar multimode (MM) VCSELs
- require less received optical power (ROP) for error-free detection than our MM devices

Summary and conclusion

980 nm VCSELs

- 177 fJ/bit (BTB; ~5 m MMF)
- 38 Gbit/s at 85°C (BTB)
- 40 Gbit/s at 75°C (BTB)
- 42 Gbit/s at 25°C (BTB)
- simultaneous high bit rate, energy efficiency, & temperature stability

- 46 Gbit/s at 85°C (BTB)
- 50 Gbit/s at 25°C (BTB)

With epi and processing refinements we anticipate . . .

- ≥ 50 Gbit/s with ≤ 100 fJ/bit at 980 nm
- ~950-1090 nm VCSELs will be the preferred VCSEL for very-short-reach and ultra-short-reach energy efficient optical interconnects

We thank . . .

http://www.iqep.com/

M. Geen, A. Joel . . . for epitaxial growth

Berlin, Germany

http://www.u2t.com/

A. Umbach . . . for providing to us a prototype 980 nm photoreceiver

Sonderforschungsbereich 787 (SFB 787)
Collaborative Research Centre

Thank you for your attention!

James A. Lott

**Dejan Arsenijević, Gunter Larisch, Hui Li,
Philip Moser, Philip Wolf**

Dieter Bimberg

Institute of Solid State Physics and Center of Nanophotonics
Technische Universität Berlin, Germany