Australian Government
Department of Defence
Defence Science and Technology Group

Characterisation of Erbium-Doped DFB Lasers Pumped Resonantly at 1480 – 1540 nm

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  - Goran
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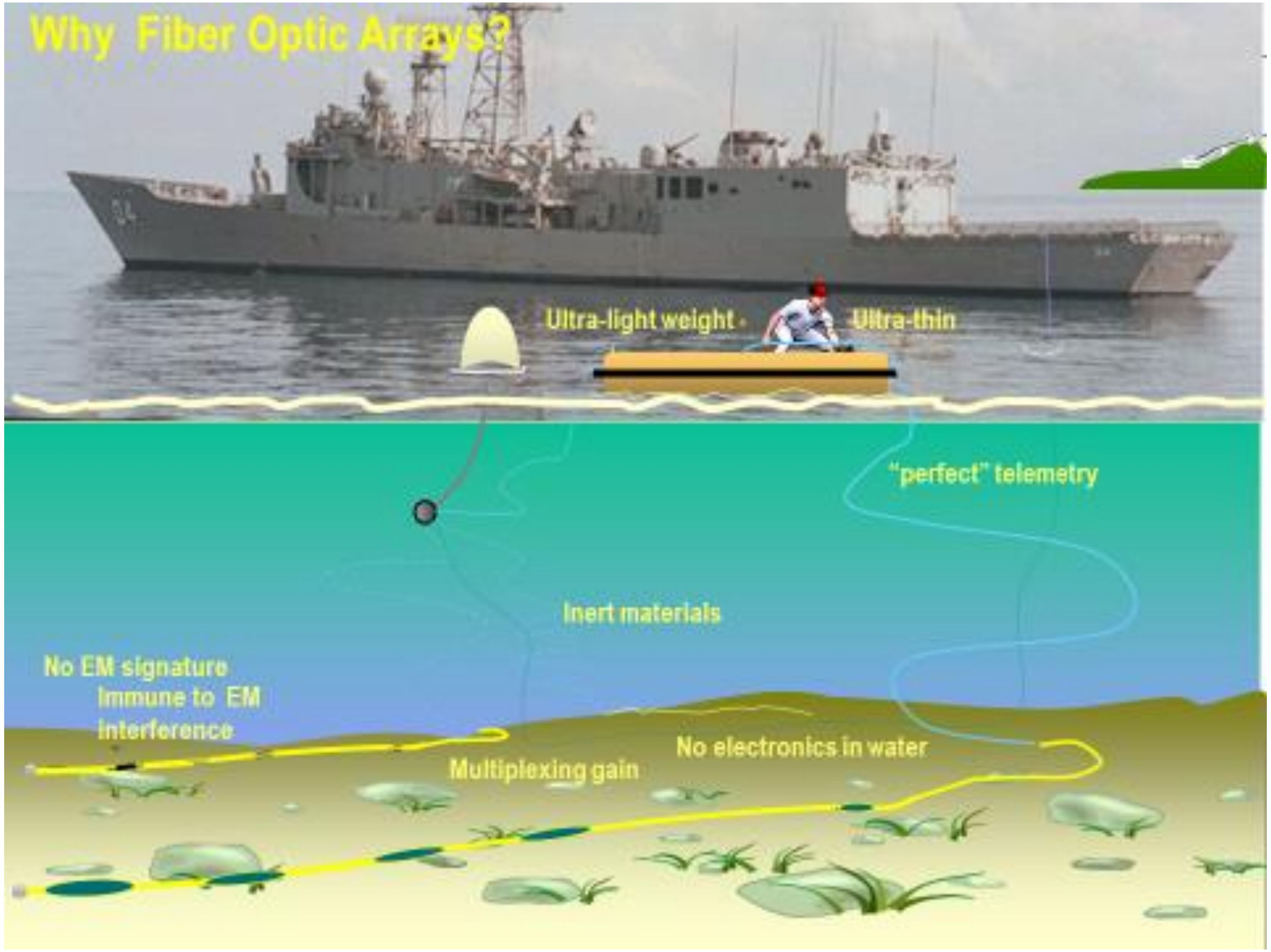
Contents

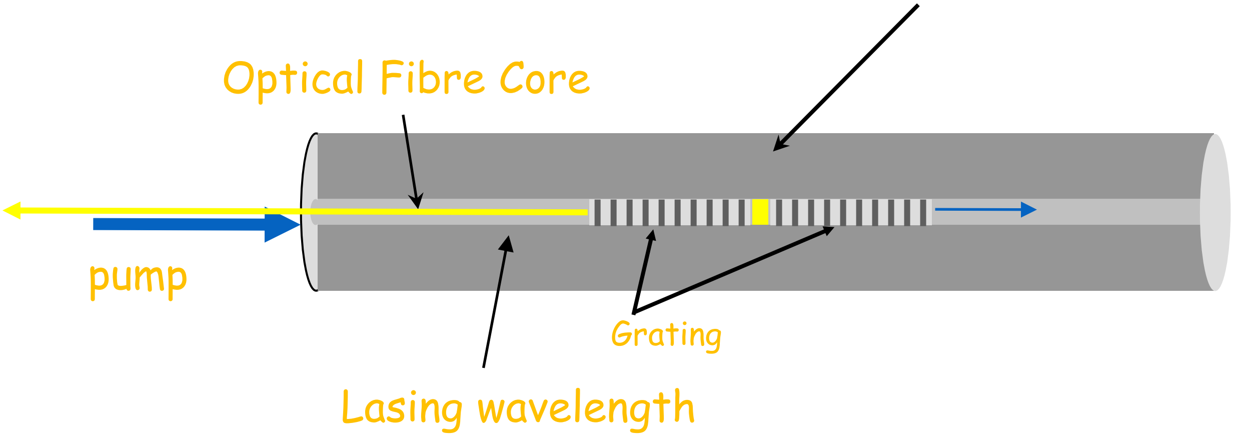
- Background in DFB laser sensing

- Ultra-remote deployment opportunities
  - What are the limitations?
  - Erbium spectroscopy
  - Resonant pumping

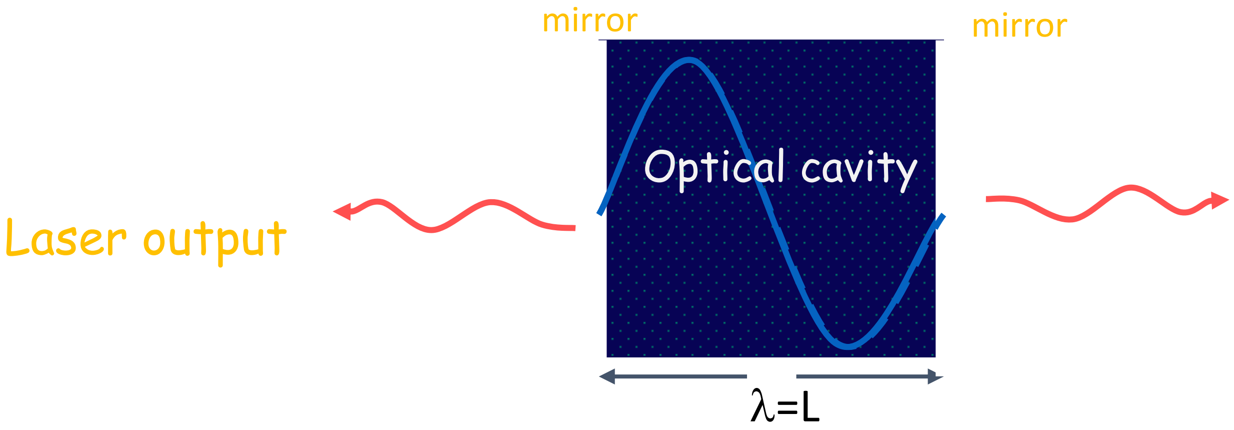
- Conclusions
- Future Work


Why Fiber Optic Arrays?
Ultra-light weight
Ultra-thin
"perfect" telemetry
Inert materials
No EM signature
Immune to EM interference
No electronics in water
Multiplexing gain

distributed feedback laser cavity in Erbium fibre

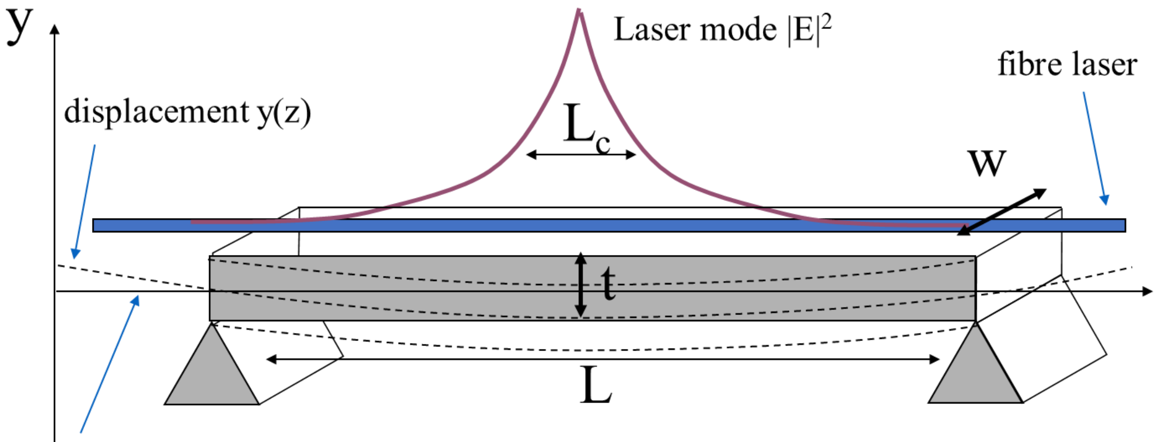


DFB FL is a very sensitive strain sensor

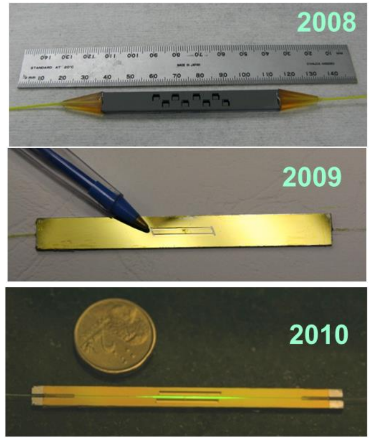


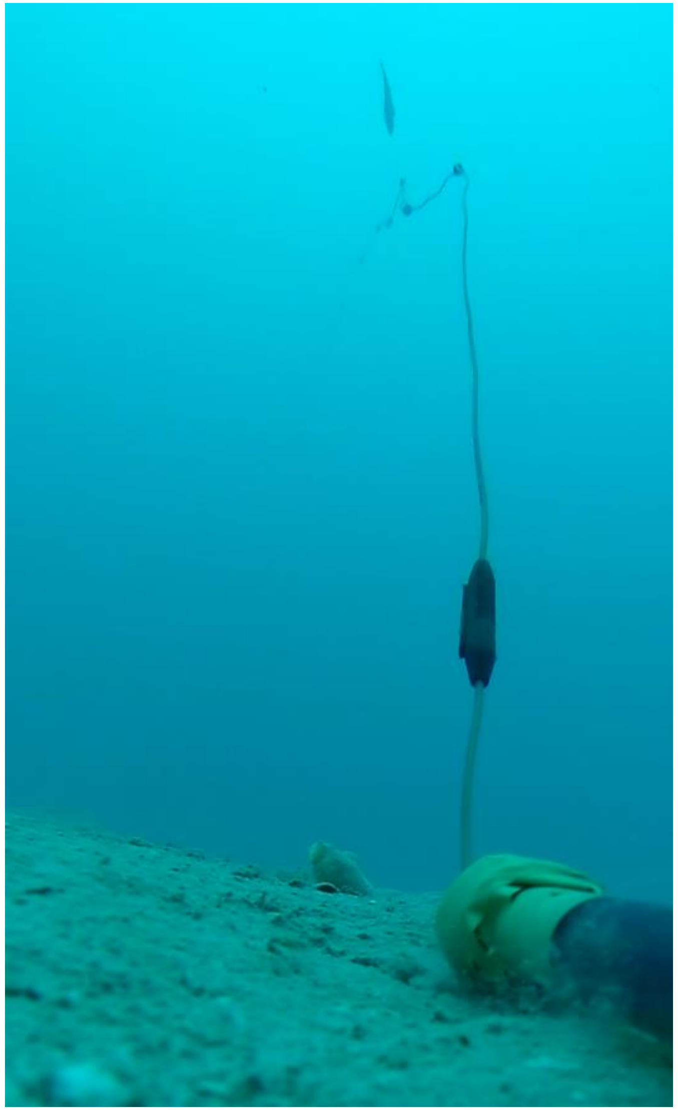
Bender transducer principle

(how to translate pressure into strain?)



$$\frac{\Delta \nu(t)}{\nu} \approx \frac{t}{2}\int \frac{d^2 y(z,t)}{dz^2}\,|E(z)|^2\,dz$$





Demonstration of fibre laser hydrophone array in Gulf St Vincent (2013)

Performance

a. Acoustic sensitivity: 105dB re Hz/Pa
b. Frequency range: 10Hz- 5kHz

Extremely small sensor footprint
Ease of demodulation
Low power requirement
It is the stable reference – no additional reference sources required for demodulation – it is the stable 'clock'
Multiplexing capability – 32 sensor arrays reported

Ultra-remote deployment

- <10 km deployments are fairly 'trivial'
  - Cranch, G. A., et al. "Large-scale remotely pumped and interrogated fiber-optic interferometric sensor array." *IEEE Photonics Technology Letters* 15.11 (2003): 1579-1581.
  - 40 km link demonstrated

- How far can this be extended for a DFB approach?
  - Pump delivery
  - Background loss management
  - Non-linearity management
  - Pump source management

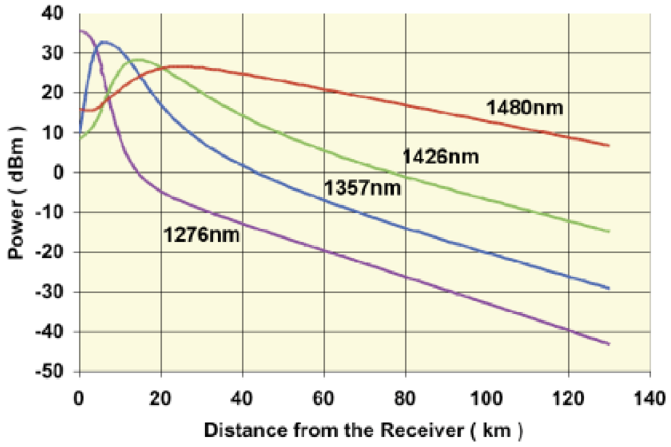
Remote pump delivery

- Remotely powered EDFAs

- Stimulated Raman Scattering becomes a limiting factor
  - Large mode area telecomm fibre is essential
  - Lowest losses essential also

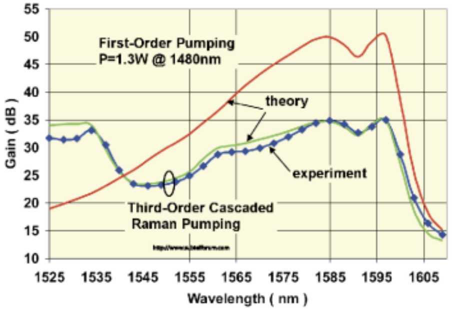
- Hollow-core fibre has an opportunity to significantly disrupt this area by allowing for a much higher power launch

Papernyi, Serguei & karpov, Vladimir & Ivanov, Vladimir & Clements, Wally & Araki, Tetsuaki & Koyano, Yasushi. (2004). Cascaded Pump Delivery for Remotely Pumped Erbium Doped Fiber Amplifiers.



Third-Order Cascaded Raman Pumping: Primary Pump and Raman Stokes Evolution along Fiber Span.

Direct 1480-nm pumping at 1.3-W leads to a very high Raman gain, limiting the maximum launched power and ultimately the power delivered to a remote EDFA. On the other hand, the third-order pumping scheme allows the delivery of ~ 2.4-dB more power at a lower Raman gain.



Raman On/Off Gain Spectra in 131 km of PSCF for first- and third- order pumping.

Propagation losses in ultra-low loss fibres

- Choice of pump wavelength begins to affect power budget at link lengths of >50 km
  - 0.16 dB/km @ 1480 nm
  - 0.146 dB/km @ 1530 nm
  - 0.142 dB/km @ 1550 nm

Y. Tamura, H. Sakuma, K. Morita, M. Suzuki, Y. Yamamoto, K. Shimada, Y. Honma, K. Sohma, T. Fujii and T. Hasegawa, "Lowest-ever 0.1419-dB/km loss optical fiber,," in Proc. Opt. Fiber Commun. Conf. 2017, Th5D.1 (2017)

- Commercially available fibres typically at +0.03 dB/km

- 150 µm^2 effective area
  - Cut-off wavelength is red-shifted
  - g_R ~ 0.19 /W/km

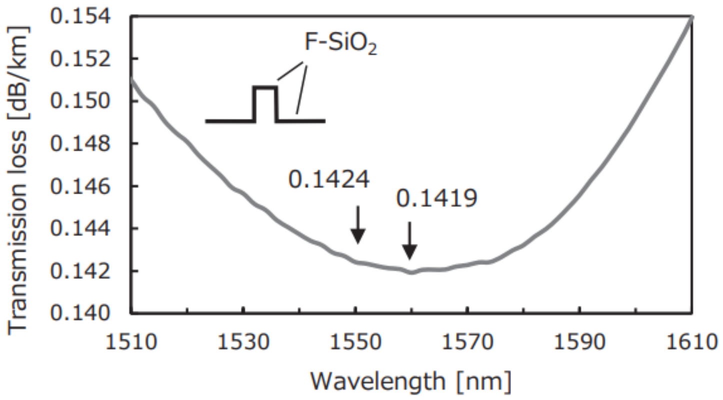


Fig. 6. Loss vs. wavelength characteristics and the structure of an extremely low-loss fiber

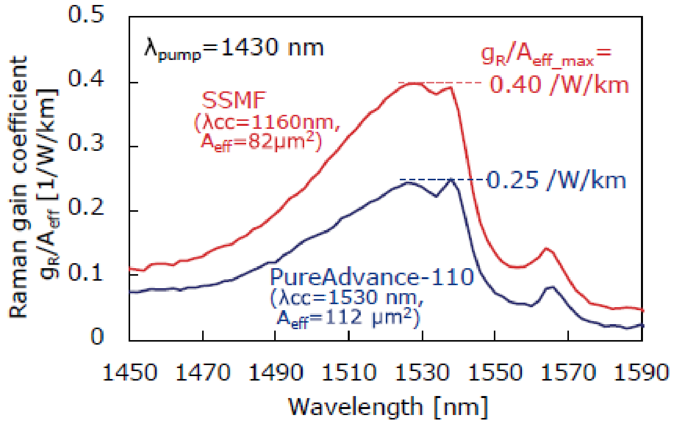
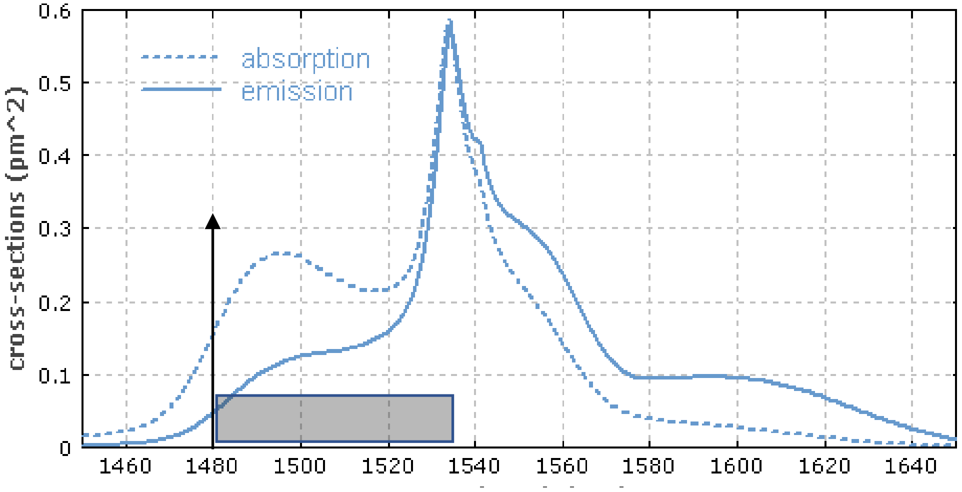


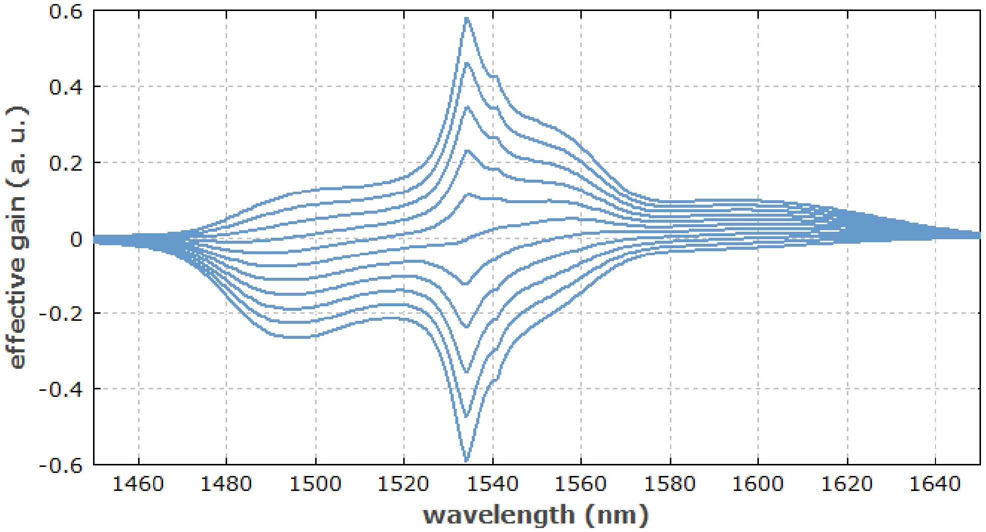
Fig. 5. Measured Raman gain coefficient

Low Loss Optical Fibers for Terrestrial Long-Haul Networks, PureAdvance

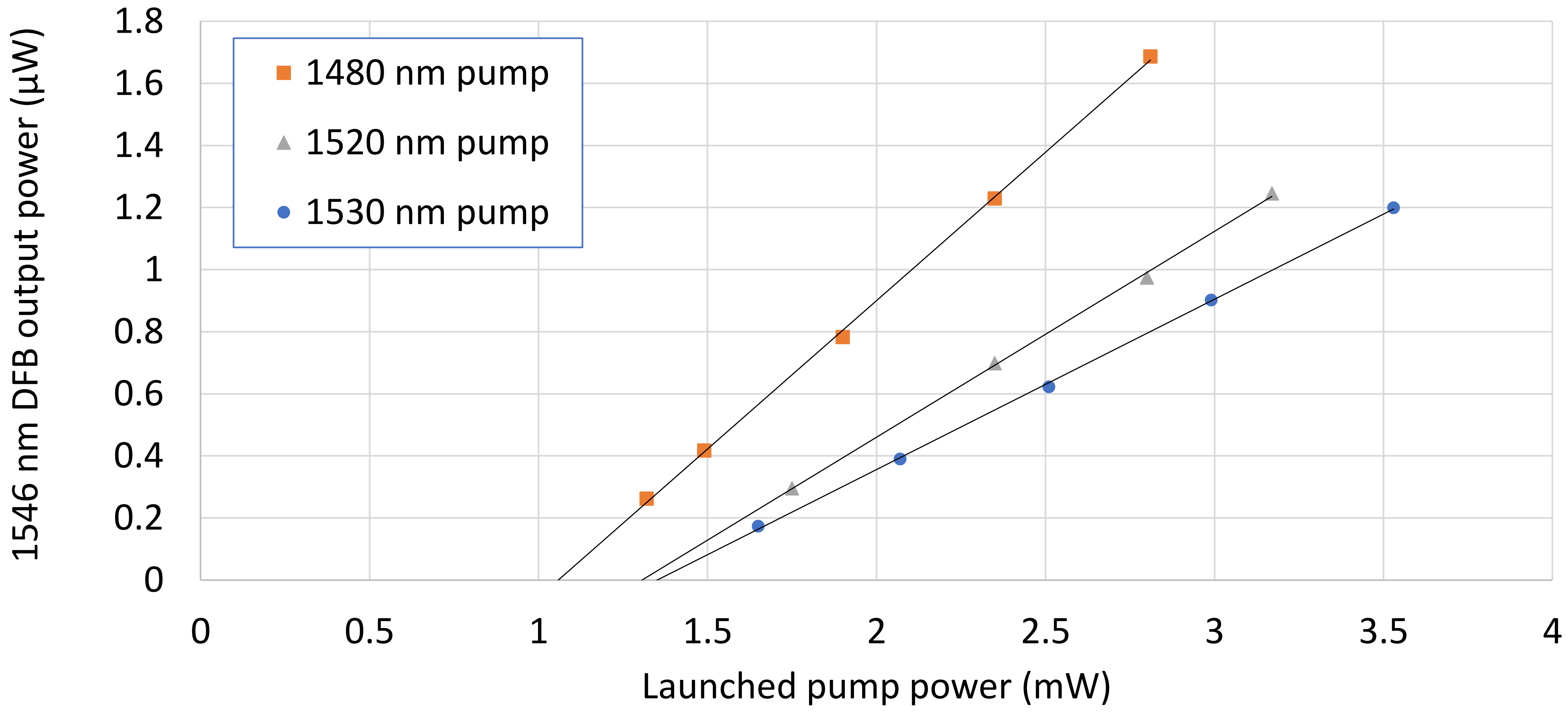
Resonant pumping of Erbium doped fibres

- Conventional pumping at 1480 nm
- Opportunity to pump at wavelengths up to 1530 nm
- Transparency and gain achieved at 30-50% inversion
  - Pump attenuation at these inversion is nearly constant from 1480 – 1520 nm
  - More interesting behavior at 1530 – 1540 nm

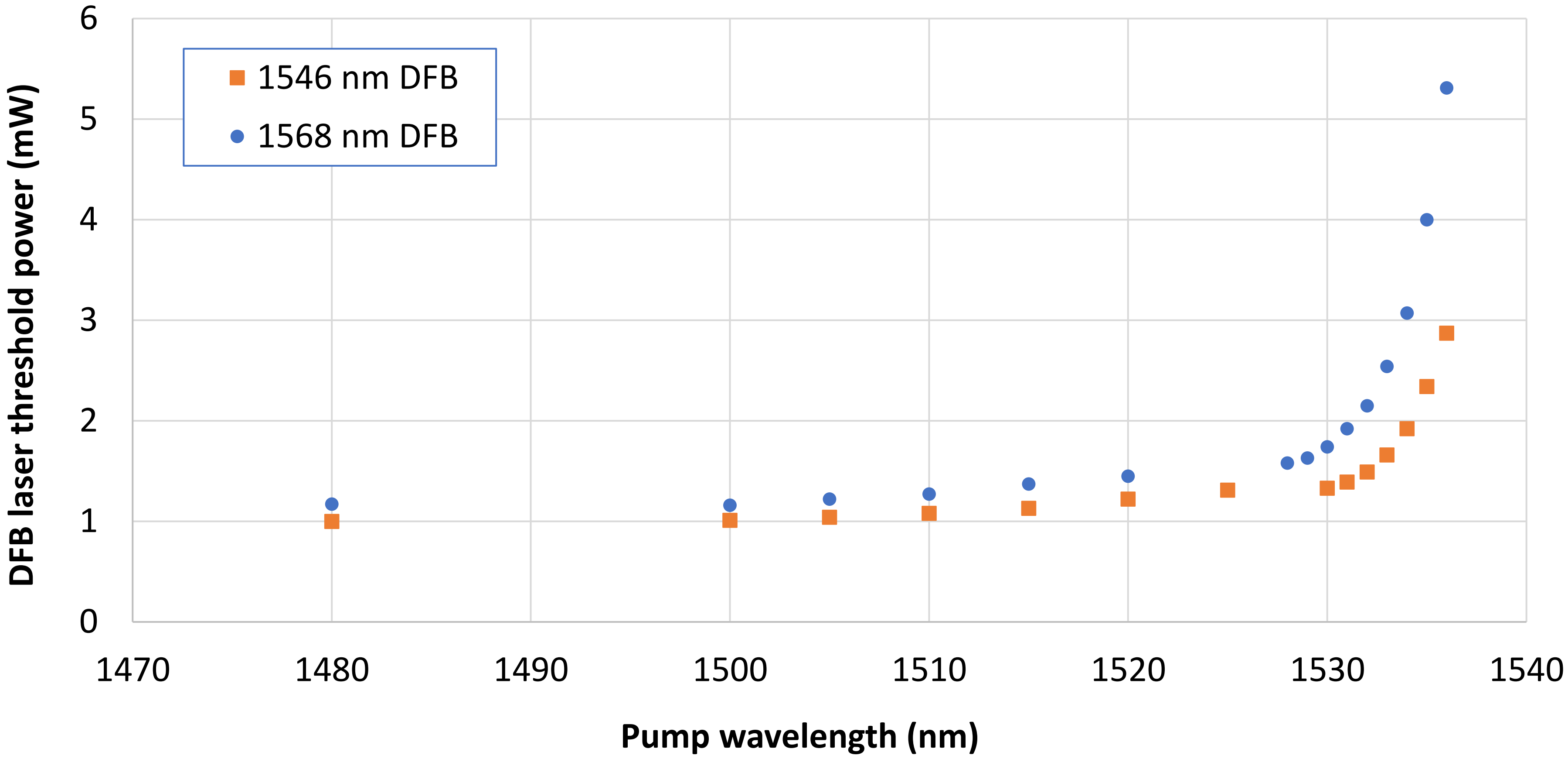




DFB performance



Pump Wavelength Dependence



Discussion

- Large parameter space of pump wavelength vs propagation loss vs required operation vs array size
  - To energise a single sensor – 2.5 - 3 mW required
  - To energise an array of 8 sensors – 20 mW required (as a minimum)

Pump	2	W
Actual length	100	km
alpha (dB/km)	0.2	dB/km
alpha (1/km)	0.02	1/km
Leff	43.23	km
G_raman	70.10	dB
Pump transmitted	20	mW

Pump	0.8	W
Actual length	100	km
alpha (dB/km)	0.16	dB/km
alpha (1/km)	0.016	1/km
Leff	49.88	km
G_raman	32.35	dB
Pump transmitted	20.10	mW

Pump	5	W
Actual length	150	km
alpha (dB/km)	0.16	dB/km
alpha (1/km)	0.016	1/km
Leff	56.83	km
G_raman	230.36	dB
Pump transmitted	19.91	mW

Pumping at 1520 nm

- Improves power budget
    - Reduces propagation loss by 0.014 dB/km

- Raman is no longer within band
    - Allows for aggressive filtering of any Raman to avoid SRS parasitics

- Compatibility with more conventional fibre types

Pump	1.26	W
Actual length	100	km
alpha (dB/km)	0.18	dB/km
alpha (1/km)	0.018	1/km
Leff	46.37	km
G_raman	47.37	dB
Pump transmitted	19.97	mW

Pump	0.5	W
Actual length	100	km
alpha (dB/km)	0.142	dB/km
alpha (1/km)	0.0142	1/km
Leff	53.40	km
G_raman	21.65	dB
Pump transmitted	19.01	mW

Conclusion

- Remote pumping of EDFAs well known/explored (100km +)
- Remote interrogation of passive sensor arrays well known/explored (40 km +)
- Here we investigate key considerations for remote pumping of Erbium DFB fibre lasers
    - Optimisation of pump source is significant in remotely deployed configurations
    - For <50 km deployment, 1480 nm pumping is suitable
    - Further optimization opens up potential for >100 km deployment of DFB sensors

- Key technologies to watch
    - Low nonlinearity/low loss hollow core fibres
    - Large mode area, ultra low loss telecomm fibres
    - Low loss fluoride fibres?
    - Low SWaP semiconductor sources at 14XX – 15XX nm
    - Further optimization of DFB devices (fibres/dopant concentration/splice losses)

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