MMF Capabilities for 400-Gigabit Ethernet, and Beyond

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List of Supporters

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Background: 850nm

- GaAs-based 850nm VCSELs, detectors
  - Basis for short-reach MMF links from 1-100Gb/s
  - Transceivers roughly $\frac{1}{2}$ the cost, $\frac{1}{2}$ the power of SM
  - GaAs detectors sensitive to maximum $\sim$870nm
- OM3 / OM4 MMF optimized for 850nm
- 850nm VCSELs viable at 28Gb/s, not likely much more
- 25Gb/s reach on OM4 limited to $\sim$100-150m by
  - Fiber: modal bandwidth, chromatic dispersion
  - VCSEL: rise/fall time, spectral width
  - Modal partition noise
- Default 1st-gen 400GbE = 16x25Gb/s (each direction)
  - line rate matches CEI-28 electrical interface
  - re-uses 2nd-gen 100GbE VCSELs, detectors, fibers
  - back-compatible with 4X100GbE (2nd-gen) modules
  - 32 fibers per bidirectional link $\Rightarrow$ new connectors
Background: Higher Speed VCSELs → InGaAs

- 25Gb/s 850nm VCSELs rumored to use InGaAs quantum well active material, rather than GaAs
  - Compressive strain leads to higher speed, lower threshold
  - But addition of Indium leads to longer wavelength, so keeping at 850nm implies very thin wells and/or InAlGaAs
  - Thus the benefits of InGaAs at 850nm are limited
- VCSELs at 860-1200nm can use much more Indium, without compromising, and achieve higher performance
- Directly-modulated VCSEL products at 40-56Gb/s are more feasible at ~860-1200nm than at 850nm
  - more 25Gb/s margin at ~860-1200nm
Advantages of Longer Wavelength

• VCSEL related
  – Higher speed (from higher differential gain)
  – Lower operating current density
  – Lower operating voltage (nearly 0.3V lower at 1060nm than 850nm)
  – Higher reliability
  – Improved thermal dissipation (GaAs in mirrors better than AlGaAs)
  – Higher temperature stability (higher well/barrier offset)
  – Single-mode emission at larger aperture (lower current density)
  – More binary-material content (GaAs replaces AlGaAs)

• Fiber related
  – Lower chromatic dispersion (and slightly lower attenuation)
  – Higher potential modal bandwidth (fewer modal groups; needs wavelength optimization to realize)

• Other
  – Higher eyesafe power
  – Higher Rx responsivity (lower photon energy; 1mW at 1060nm has about 1dB more photons/sec as 1mW at 850nm)
InGaAs VCSELs and detectors

• 860-1200nm InGaAs VCSELs are **NOT** “1310nm VCSELs”
  – Extending VCSEL wavelength to 1310nm region must incorporate Nitrogen into the active material ➔ loss in performance

• 860-1200nm InGaAs VCSELs **better than** “850nm VCSELs”
  – Adding Indium into the active material ➔ improved performance, as outlined in previous slide

• 840-1300nm InGaAs 10Gb/s detectors: commercial products
  – Similar to standard InGaAs 1260-1355nm detectors, but with (straightforwardly)-modified top conductive layer(s)
  – Extend to 28Gb/s and faster, similarly as for GaAs or other InGaAs detectors
Reaching 100m on OM4 at longer wavelengths

- Lower MBW requires faster rise/fall times, which should be achievable at the longer wavelengths
- Used “Example MMF Link Model” posted as supporting petrilla_04_0513; changed wavelength, MBW, responsivity
- 100m on OM4 up to about 960nm
Longer-wavelength Gen1 options for 400GbE

• 16x25Gb/s at ~950nm
  – 100m reach on OM4
  – back-compatible with 4X100GbE (2^{nd}-gen) modules*
  – ~200m reach on “OM4-950” (OM4-quality MMF optimized for 950nm) with 16ps rise/fall time
  – **200m reach objective?**
  – 100m reach on “OM4-1060”
  – Better-suited for future-gen faster line rate (CEI-56)

• 16x25Gb/s at ~1060nm
  – <100m reach on OM4
  – back-compatible with 4X100GbE (2^{nd}-gen) modules*
  – ~250m reach on “OM4-1060” with 16ps rise/fall time
  – **200m reach objective?**
  – Better-suited for future-gen faster line rate (CEI-56)

* Requires broadband (840-1060nm) detectors on 100G modules
CWDM option for 400GbE

• 16x25Gb/s CWDM at e.g. 850, 885, 920, 955nm
  – 100m reach on OM4 (fast rise/fall for longest wavelength)
  – 4 fibers each direction!
  – NOT back-compatible with 4X100GbE (2\textsuperscript{nd}-gen) modules
  – Back-compatible with 4X100GbE (3\textsuperscript{rd}-gen-CWDM) modules
    (100GbE on duplex OM4 fiber!)
  – Detectors: broadband InGaAs (840-965nm)
  – Gen1 readiness?? If not, then Gen2?

• 16x25Gb/s CWDM at e.g. 1000, 1040, 1080nm, 1120nm
  – <100m reach on OM4
  – 4 fibers each direction!
  – NOT back-compatible with 4X100GbE (2\textsuperscript{nd}-gen) modules
  – ~150m reach on “OM4-1060” (16ps rise/fall time)
  – Back-compatible with 4X100GbE (3\textsuperscript{rd}-gen-CWDM) modules
    (100GbE on duplex OM4 or “OM4-1060” fiber!)
  – Detectors: same InGaAs as for SMF; diameter for MMF
  – Probably not Gen1; maybe Gen2?
Gen2/3 options for 400GbE

- **8X50Gb/s at 850nm** – VERY UNLIKELY
- **8X25Gsym/s w/ 2X PAM/QAM at 850nm** – UNLIKELY
- **CWDM with wavelengths less than 850nm** – VERY UNLIKELY

- **8X50Gb/s at ~1060nm**
  - 50Gb/s needed with introduction of CEI-56
  - 100m reach on “OM4-1060” (based on ~250m at 25Gb/s)
  - 8 fibers each direction

- **8X25Gsym/s w/ 2X PAM/QAM at ~1060nm**
  - 50Gb/s
  - 200m? reach on “OM4-1060” (based on ~250m at 25Gb/s)
  - 8 fibers each direction
New MMF worth considering

• “OM4-XXXX”
  – relatively straightforward development (tweaked OM4)
  – >200m reach at 25Gb/s at optimal wavelength
  – 100m reach at 25Gb/s at ±110nm from optimal wavelength
  – fibers not meeting spec could be “OM3-XXXX” for 100m
  – CWDM over reduced distance

• CWDM over “OM4-1060”
  – 100m reach for 955-1165nm range @25Gb/s (≥16ps r/f)
    • 955, 985, 1015, 1045, 1075, 1105, 1135, and 1165nm (8 λ's, 30nm spacing)
  – est. 50m reach @50Gb/s
  – est. 75m reach @25Gsym/s w/ 2X PAM/QAM
  – Longer reaches for 4 wavelengths and/or tighter λ spacing
1.6Tb/s and 6.4Tb/s MMF possibilities

• 400Gb/s
  – 8 wavelengths at 50Gb/s over 50m duplex “OM4-1060”
  – 8 wavelengths at 25Gsym/s (2X PAM/QAM) over ~75m duplex “OM4-1060”

• 1.6Tb/s
  – same as 400Gb/s over 4+4 fibers

• 6.4Tb/s
  – same as 400Gb/s over 16+16 fibers
Summary

- MMF / VCSEL platform has delivered optical links at ~1/2 the cost/power of SMF links from 1Gb/s to 100Gb/s
- Technically-viable approaches can extend the platform to at least 6.4Tb/s – MMF has legs!!
- Approaches focus on
  - longer-wavelength VCSELs (higher speed)
  - longer-wavelength-optimized fibers (longer reach)
  - use of off-peak wavelengths in fibers (for CWDM)
  - CWDM mux/demux optics for MMF

- 200m reach objective merits 400G SG consideration