Vixar

Use of Red VCSELs in POF-Based Home Networking

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Contents

1 Executive Summary

This paper specifically addresses the need for optical sources optimized to meet the needs of the emerging 1 Gbps POF-based Home Networking market. Three technologies that can practically be considered to meet the requirements of this application are compared, all in the visible red region of the spectrum: VCSELs, RCLEDs, and F-P lasers. Recent advances in the design of red, communications grade[1] VCSELs to perform and survive at higher operating temperatures result in this technology being superior to that of RCLEDs and F-P lasers for the 1Gbps POF-based home networking application.

2 POF Background

There are multiple types of polymer optical fiber that can be called "POF". The differences between POF types are the polymer material used in the core (determining the attenuation and the operating temperature range) and the index profile (responsible for mode dispersion and therefore the bandwidth). The diameter of POF cores also varies between POF-type products, affecting the number of modes and therefore bandwidth.

Step-index, POF (SI-POF) with a core made of PMMA[2] (polymethyl methacrylate) and a diameter of 1mm is the least expensive and readily available from many vendors with consistent quality. There are many compatible components and measuring instruments for 1mm SI-POF as well as experimental data available (e.g. lifetime data).

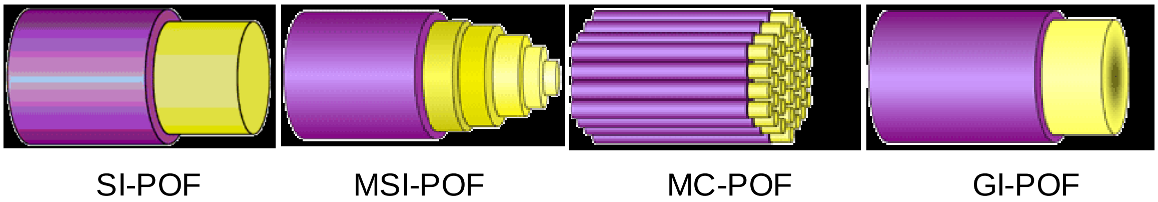


Figure 1: POF Index Profiles

[1] Vixar uses the term "Communications Grade" to refer to VCSELs designed for high output power and operation at higher temperatures, as is often required in data communications applications. A VIXAR Application Note titled "Reliability of VIXAR's Red VCSELs" gives a more detailed explanation, and is available upon request.

[2] Brand names of PMMA include Plexiglas® and Lucite®

Due to its much lower cost, SI-POF (1-mm standard SI-POF as specified by IEC 60793-2 A4a.2) is the type of POF that is the focus for standardization efforts related to POF-based home networking. Because of this, **we will use "SI-POF" to refer to polymer optical fiber that complies with this standard for the remainder of this paper, we will use "POF-based home networking" to imply use of SI-POF**.

The other types of polymer optical fiber listed below were designed to increase the practical bandwidth by reducing attenuation (PF GI-POF), reducing chromatic dispersion by improving the index profile (GI-POF, MSI-POF), or creating multiple physical light paths to improve the index profile while maintaining the ease of coupling input light (MC-POF). For example, the attenuation profiles of both SI-POF and PF GI-POF are shown in Figures 1 and 2, respectively, below.

- SI-POF[3]: Step-index POF
- MC-POF: Multi-core POF (n times bandwidth of SI-POF, where n= no. of cores)
- MSI-POF: Multi-step-index POF (40 X bandwidth of SI-POF)
- GI-POF: Graded Index POF (100 X bandwidth of SI-POF)
- PF GI-POF: Perflourinated (i.e., non-PMMA) GI-POF (>100 X bandwidth of SI-POF)

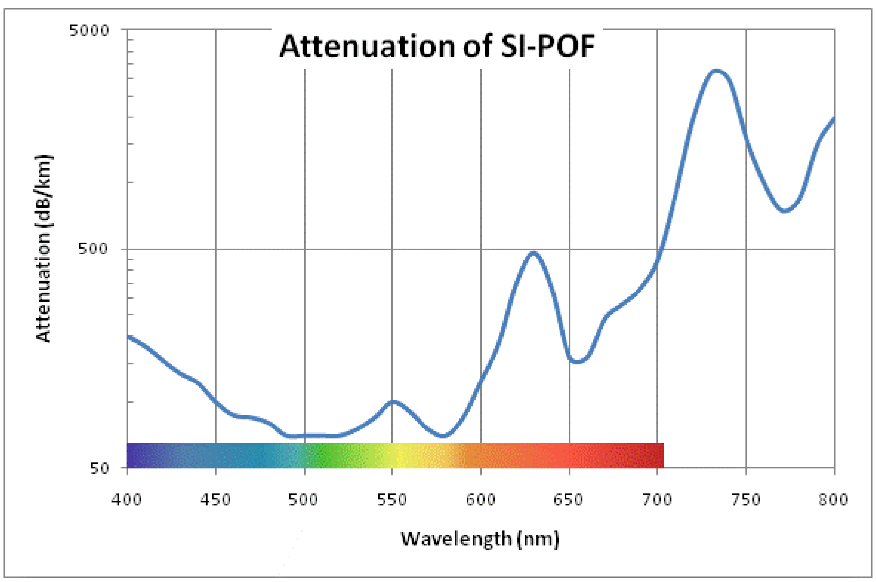


Figure 2: SI-POF Attenuation [3]

[3] 1-mm standard SI-POF as specified by IEC 60793-2 A4a.2

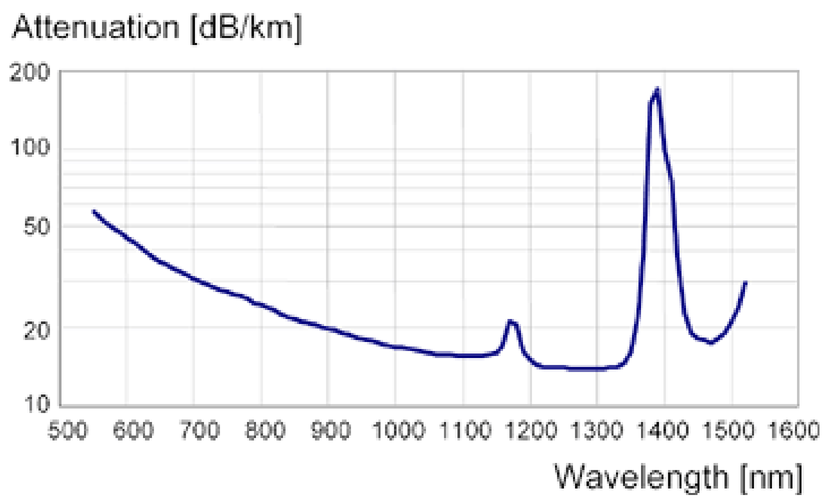


Figure 2: Attenuation Profile for PF (non-PMMA) GI-POF [8]

For years SI-POF has been widely used in industrial field buses for controlling process equipment in rugged manufacturing environments, and in automobiles to connect an increasing array of multi-media equipment.

The main advantages of SI-POF when compared to glass optical fiber (GOF) are [1]:

- **Less expensive fiber optic material.**
- **Easier to couple.** SI-POF large core diameter (1mm) allows do-it-yourself installation and termination with common cutter and electrician-like low cost tools.
- **Less sensitive to bending.** SI-POF high diameter and numerical aperture makes bending loss sensitivity much lower than GOF.
- **Less sensitive to mechanical stress.** SI-POF mechanical resilience and elasticity makes it possible to step on it and even tie it. Dust and water harm SI-POF to a much smaller extent than GOF.
- **Easier to troubleshoot.** The optical sources for SI-POF are in the visible range and therefore easy to troubleshoot, as the signal can be seen by the naked eye.

Key advantages when compared to the more traditional copper cabling include [1]:

- **Complete immunity to electromagnetic interference** (EMI). POF is an electrical insulator (like GOF), so it can be laid down in power ducts. This apparently minor issue is seen as a key element by several European telecommunications companies for in-house installation in brown-field areas.

- **Lower weight** (a fundamental issue in the automotive sector).

3 Application Dictates Specifics of POF Physical Layer

The requirements for applications that utilize POF differ significantly in terms of bandwidth, link length, bend loss and operating temperature range, as illustrated in the table below. Therefore, each application may require a different physical layer, which includes not only the POF itself (i.e., SI-POF vs. GI-POF vs. PF GI-POF) as discussed earlier, but also transmitters (light sources) and receivers.

Application	Bandwidth	Reach	Temperature
Industrial bus	~100Mbps	100 m	-40 to 85 °C
Automotive media	400-800 Mbps	18 m	-40 to 125 °C
Home networking	0.2-1.25Gbps	100 m	0 to 60 °C
Backplane	2.5-10 Gbps	<< 1 m	0 to 70, or 85C

4 Emergence of the POF-Based Home Networking Market

The adoption of POF by the IEEE 1394.b standard in the early 2000s opened up additional opportunities for using POF in consumer applications such as home networking; however, this market has not begun to emerge until recently as the demand for delivery of the triple play (audio, video, data) to the home with increasing resolution (e.g., HDTV) becomes a reality. A critical missing piece is a standard specification for the physical layer of a SI-POF-based home network. To achieve wide acceptance, a VDE POF Working Group is developing 1 Gbps SI-POF standards proposals: first for Europe, and then more broadly internationally. The goal of this working group is stated below.

> "This working group aims to fill the gap in POF standardization. It is the objective of the team to design a robust and easy-to-install transmission system for data rates of 1 Gbit/s over up to 50 m transmission distance." [1]

At the present, most component and equipment suppliers are unsure what specifications for the physical layer of POF-based home networking[4] (i.e., transmitters, receivers, connectors, etc.) will prevail in the marketplace, so some may be reluctant to invest in developing or launching POF-oriented home networking products. On the other hand, other suppliers are developing and launching products prior to any formal standardization of the physical layer. Obviously, the sooner standards for POF media and transmission/modulation/encoding schemes are set, the sooner POF-based home networking market will take off.

Aside from the need for standards, POF optical network systems have been proven to function in field tests by European telcos which promote this medium as an easy-to-install, lower cost (based on installation time and tools savings), flexible, eye-safe solution for both home networks and commercial use. A report from AT&T also promotes POF-based home networking. [2]

5 Optical Source Requirements for POF-Based Home Networking

The ideal light source for any fiber optic cable, including POF, has low divergent, circular beam patterns ideal for efficient coupling to fiber, exceedingly low threshold currents (a few mAs) and high bandwidth (several GHz). It also is visible and eye-safe.

Table 1, below, illustrates the ability of the obvious light source contenders to meet the requirements for POF-based home networking optical sources using the attenuation dip in the red region of the spectrum.

[4] In this paper, POF-based home networking implies the use of SI-POF as the fiber.

Characteristic		Requirement	VCSEL	RCLED	F-P Laser
Distance-Bandwidth Product (Note 6)	Modulation Bandwidth (Note 1) [5]	1.25Gbps over 50m 1 Gbps over 100m	**5 GHz**	**150 MHz**	**2 GHz**
	Beam divergence (Note 2)		15° FWHM	50° FWHM	15° x 40°
	Spectral Width (Note 3)		1-2nm	4nm [4]	2nm [4]
	Nominal Wavelength (Note 4)		650-670nm	650nm	650nm
	Δλ/ΔT [nm/K] <0-60°C>		0.043	(Note 12)	0.180 [4]
	Nominal Power (Note 5)				
	ΔPopt/ΔT [dB/K] <0-60°C>		**-0.08**	-0.03	-0.02
Operability & Reliability	Threshold Current	(Note 10)	<1mA [6]	0mA	25 mA [5]
	Operating Current	(Note 10)	10mA	20mA	40mA
	TT1%F @ 60C° (Note 7)	~5 years	>4.5 years (Note 9)	not available	not available
Transmitter Cost (Note 8)		(Note 11)	<$5	<$5	~$20

Table 1: POF-based Home Networking Optical Source Alternatives [4], [5], [6]

Notes:

(1) Largely determined by rise time. For example, in VCSELs the rise time is 35-100 picoseconds, whereas in RCLEDs it is ~1 nanosecond (10-30 times that of VCSELs).

(2) Fiber optic cable coupling efficiency improves with smaller, circular beam divergence.

(3) Small spectral width reduces chromatic dispersion, therefore increasing the effective bandwidth over fiber.

(4) There are currently no light sources for the lowest POF attenuation areas near 570 nm and 450-530 nm that come close to satisfying the bandwidth and cost requirements of POF-based home networking; therefore, the focus is on the low attenuation area in the red region (i.e. ~650nm).

(5) All 3 technologies meet the minimum required output power. Maximum output power is limited by eye safety regulations unless implemented using Active Optical Cable technology.

(6) Minimum 1.25 Gbps at 50 meters [1].

(7) According to [1], the required operating temperature range is 0-60°C and the required operating humidity is up to 85%.

(8) Considering both the cost of the light source and the cost associated with the mounting of the light source, which, in the case of F-P lasers, is considerable.

(9) Results achieved on VIXAR's 670nm VCSELs at 60C° (dry). VIXAR does not yet have failure information for our red VCSELs at 60C° and 85% humidity.

(10) Lower values are desirable to minimize power consumption.

(11) Lower costs increase market penetration since POF-based home networking is a consumer product.

(12) RCLED values for this depend on specific design parameters, and can range from the value for VCSELs to the value for F-P lasers (including edge emitting lasers).

6 VCSEL Technology's Ability to Meet Requirements Today

The sections below show evidence that Vixar has advanced the design of red, communications grade VCSELs to meet the characteristics in Table 1 (above) and meet the requirements of POF-based home networking.

6.1 Output Power over Temperature

Red VCSELs have traditionally had difficulty performing adequately at higher temperatures. Advances in recent years at Vixar have resulted in red, communications grade VCSEL designs that perform well at the temperature range required for POF-based home networking (i.e., 0-60°C). As can be seen, these devices meet the power-at-temperature requirement for POF-based home networking, and they do this at a very low current.

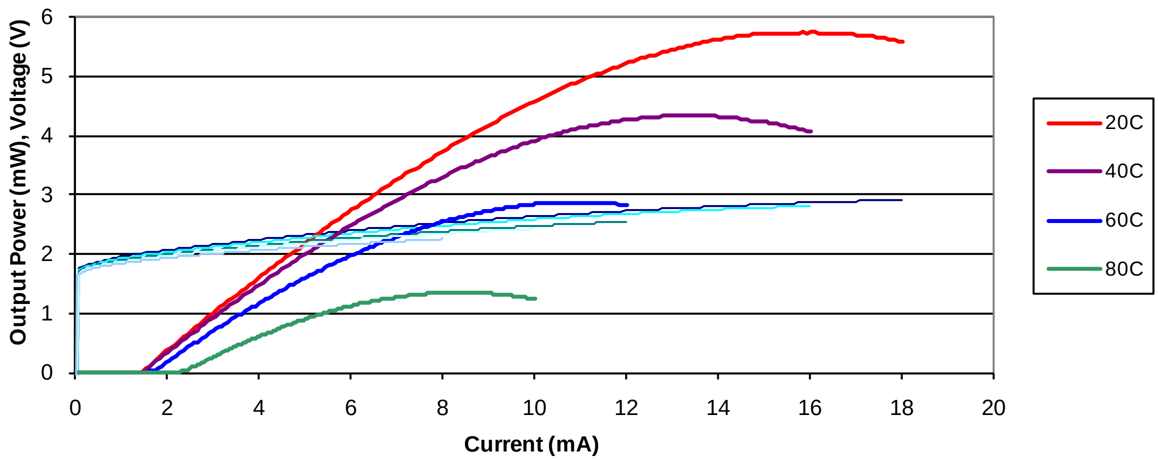


Figure 3: VIXAR's Communications Grade Red VCSEL

6.2 Reliability at High Temperature

The reliability of red VCSELs at high operating temperatures has also been a traditional shortcoming of red VCSEL technology. As can be seen from the figures below, Vixar has refined a red, communications grade VCSEL design that has excellent reliability in an environment of higher temperatures (i.e., over 4.5 years until failure of 1% of devices).

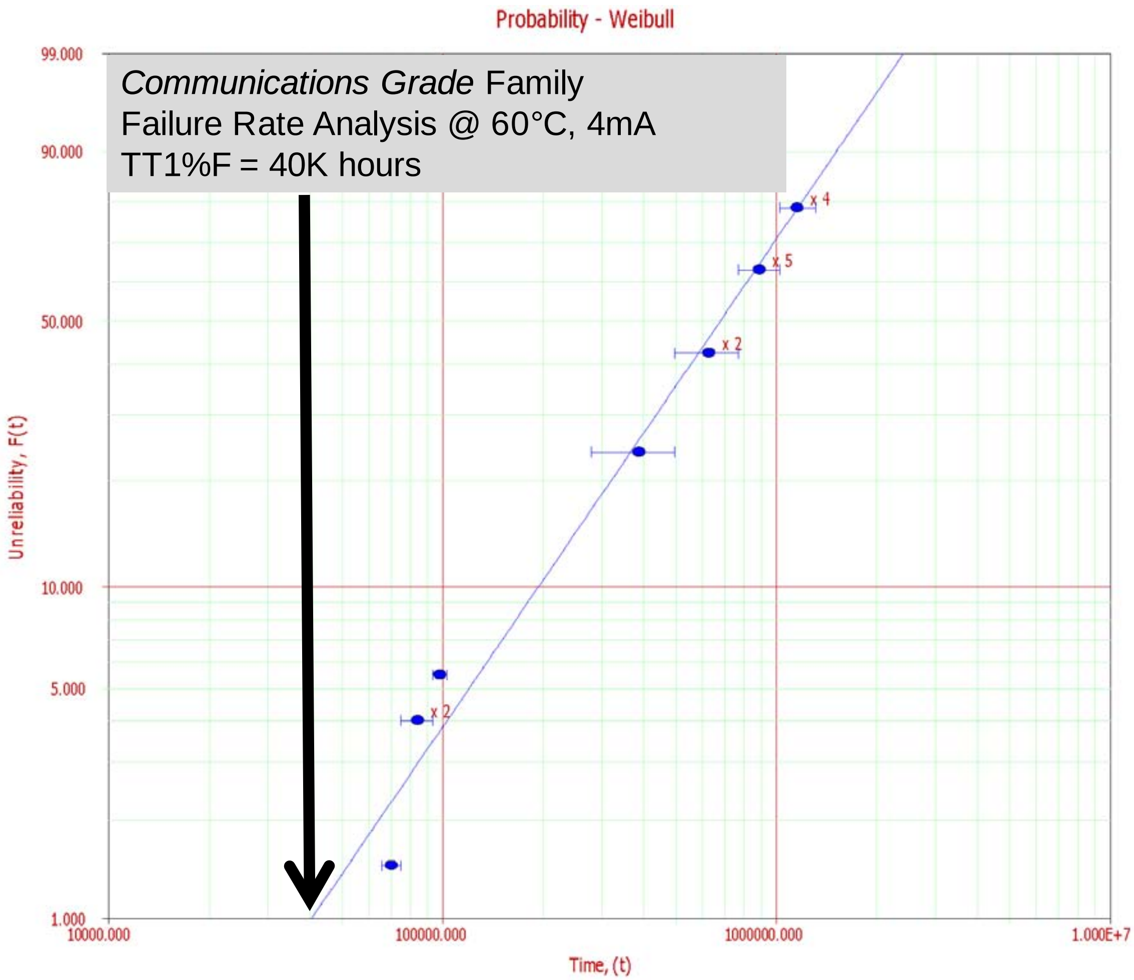
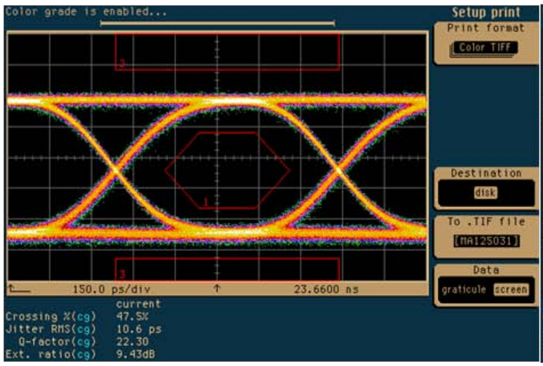
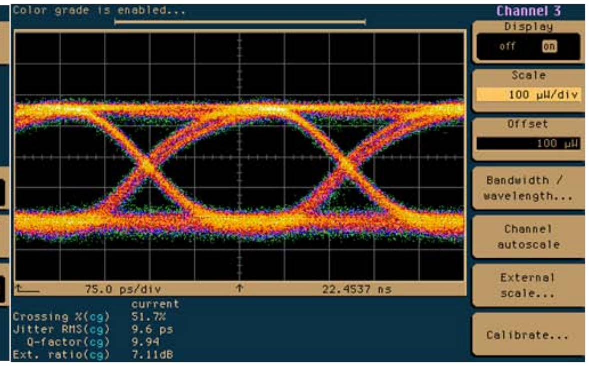


Figure 4: Failure distribution of VIXAR's Communications Grade red VCSELs.

6.3 Data Rate

Vixar has done a study of various drivers and determined which deliver the best modulation results in combination with our VCSEL design. The results are below, and clearly demonstrate the ability of red VCSELs to deliver excellent results up to at least 3 Gbps.





1.25 Gbps 3 Gbps

6.4 Wavelength over Temperature

Wavelength as a function of temperature (Δλ/Δ°K) is 0.045nm/°K for 650-670nm (i.e., red) VCSELs. This is not a function of VCSEL design, but rather is a physical constant that holds for all VCSELs of this wavelength. Over the operating temperature range of 0-60°C, the wavelength shift due to temperature is therefore ~2.7nm, which would cause a change in attenuation of ~1dB/100m in the steep portion of the attenuation profile above 650nm (i.e., ~660-670nm).

To put this in context, a likely competing POF-based home networking light source technology, edge-emitting lasers (EELs), have a Δλ/Δ°K four times greater than VCSEL technology. Therefore, the attenuation increase is four times that of VCSELs.

7 Conclusions

With the appropriate expertise and focus, red VCSEL technology can meet the requirements of POF-based home networking for bandwidth and reliability over the 0-60C° temperature range. Proof of this exists in VIXAR's Communications Grade Red VCSEL products.

Given this, VCSELs that meet these requirements are superior to alternative light sources for POF-based home networking applications due to their significantly lower cost and ability to reach even faster data rates when compared with the other potential light sources for this application.

References

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