NEW PHASE STABLE OPTICAL FIBER

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Abstract

Linden Photonics offers a standard single mode fiber with a special liquid crystal polymer (LCP) coating. This material has a negative coefficient of thermal expansion, which significantly reduces the change of signal delay due to temperature change. Other than with normal fiber cables, the thermal coefficient of delay (TCD) is not in the range from 40 to 130 ps/km/K, but below 7 ps/km/K. Thus it is nearly as good as the phase stabilized optical fiber (PSOF) by Furukawa (specification < 5 ps/km/K). The TCD of Linden Photonic cables have been measured at DESY. In order to make this comparable, the PSOF by Furukawa and furthermore three standard optical fiber cables were measured, too. As a result, a complete picture of the TCDs of different fibers will be presented. This information is very useful in order to design optical synchronization systems in general. It is planned to use Linden Photonics cables for the long links (fiber lengths in a range from 0.4 to 3.5 km) of the laser based synchronization system at XFEL.

INTRODUCTION

In the laser based synchronization system at FLASH [1], delay changes of 300 ps have been observed on fiber links with a length of up to 400 m. The latest link stabilizations units are able to compensate delay changes of about 666 ps [2]. Assuming the same delay changes at XFEL and scaling them to a length of 3.4 km, it is desirable to reduce the delay change by at least a factor of 5 to below 666 ps. Thus, the same link stabilization used at FLASH can be used at XFEL. The reduction of the delay change can be achieved by using a phase stable optical fiber instead of a conventional one. Furthermore, such cables are always useful on fiber links were an active stabilization is not possible.

THEORY

The *TCD* of a fiber that is mechanically coupled with the jacket can be calculated [3]

$$TCD = \frac{1}{c}\left[\underbrace{N_g K}_{expansion} + \underbrace{\frac{dN_g}{dT}}_{temperature} + \underbrace{\frac{dN_g}{d\sigma} E_f\left(K - k_f\right)}_{stress}\right] \quad (1)$$

$$K = \frac{A_f E_f k_f + A_j E_j k_j}{A_f E_f + A_j E_j} \quad (2)$$

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With c speed of light in vacuum, $N_g = 1.4682$ group index, T temperature, dN_g/dT group index temperature dependence (thermo-optic coefficient), σ stress in the fiber, $dN_g/d\sigma = -4.27\cdot10^{-12}$ Pa^{-1} group index stress dependence [4], $E_{j,f}$ Young's modulus, K, $k_{f,j}$ coefficients of thermal expansion, $A_{f,j}$ cross-sectional areas (the subscripts "f" and "j" refer to the fiber and the jacket, respectively). The parameters in Tab. 1 will be applied.

Table 1: Assumed Cable Material Parameter

Material	***E*** **[N/mm²]**	***k*** **[K^{-1}]**
Fiber	71700	$0.56\cdot10^{-6}$
LCP_{Linden} [4]	20000	$-6\cdot10^{-6}$
Aramid [5]	90000	$-2\cdot10^{-6}$
Santoprene [4]	3	$100\cdot10^{-6}$

TESTED CABLES

250 µm tight buffered: Most standard single mode fibers (SMFs) have a thin tight buffered jacket (Fig. 1a). This jacket is mechanically coupled with the SMFs and consists typically of a soft material [7, 8], or more precise $E_f k_f >> E_j k_j \Rightarrow K \approx k_f$. So the jacket has no impact on the *TCD* of the bare fiber. While the parameters c and N_g are well known, the existing information on dN_g/dT is both $9.2\cdot10^{-6}$ K^{-1} [4] and $12\cdot10^{-6}$ K^{-1} [6]. From these values and Eq. 1 and 2 results a *TCD* range from 33.4 to 42.7 ps/km/K†.

STFOC: The Strong Tether Fiber Optic Cable (*STFOC*) from Linden Photonics has a 250 µm tight buffered cable core, followed by an tight buffered LCP coating‡ and a soft outer jacket (Fig. 1b) [4]. Only the LCP coating will be taken into account and thus *TCD* = 11.1 ps/km/K.

Non-Kink STFOC: The *Non-Kink STFOC* consists of an *STFOC* plus an aramid braid and a Santoprene coating in order to make it more robust (Fig. 1c). The aramid braid is tight buffered, but not mechanically coupled with the *STFOC* [4]. First it was assumed that the *TCD* will be the same as *STFOC* without an aramid braid.

PSOF: In Fig. 1d the *PSOF* from Furukawa can be seen. The main difference compared with the *STFOC* is a thicker soft jacket of silicone resin in between the SMF and the LCP coating [8]. The *TCD* is specified < 5 ps/km/K.

† For all following calculations we use $dN_g/dT = 9.2\cdot10^{-6}$ K^{-1}.

‡ Customised coefficient of thermal expansion (see Tab. 1)

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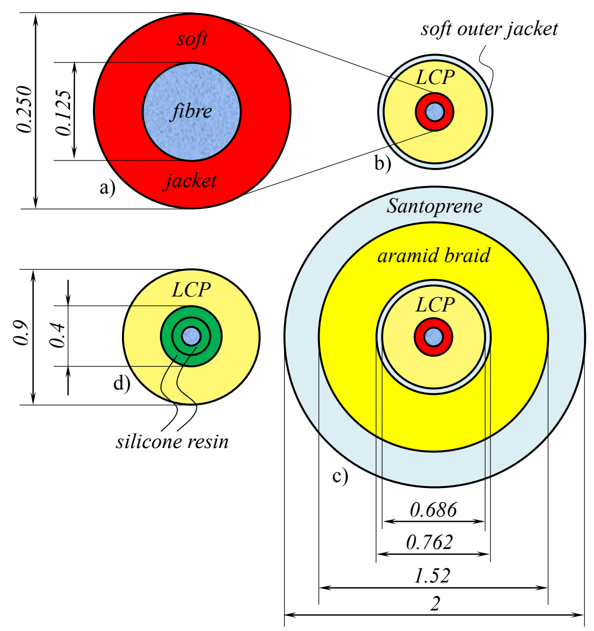

Figure 1: Tested cable types with LCP. a) 250 µm tight buffered, b) STFOC, c) Non-Kink STFOC, d) PSOF.

Loose tube: A common *loose tube cable* with *250 µm tight buffered cables* inside is shown in Fig. 2a [9][§]. The inner diameter *ID* >> 250 µm and so this can really be considered a loose tube cable, which means that the coating has no effect on *TCD*.

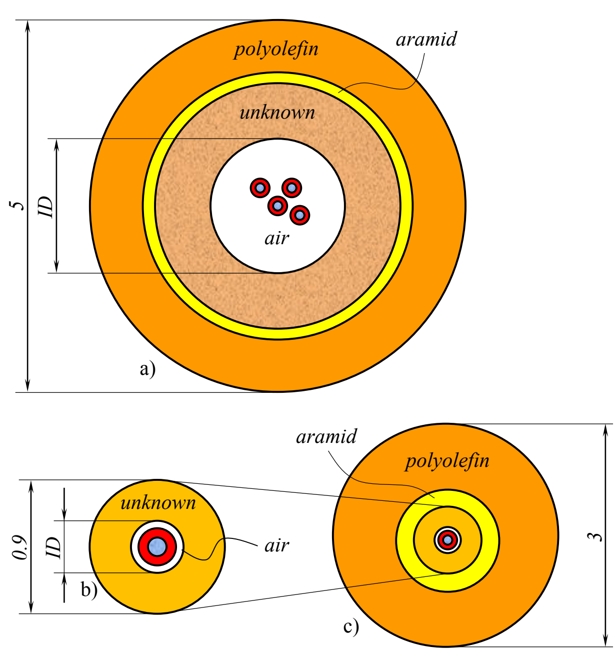

Figure 2: Tested conventional cable types. a) Loose tube, b) 900 µm semi-tight tube, c) 3 mm semi-tight tube.

900 µm semi-tight tube: The semi-tight tube cable type in Fig. 2b [9][**] is often used for optical component pigtails. Here, the inner diameter is only slightly larger than the 250 µm outer diameter of the tight buffered cable. So it can be neither considered a loose tube nor a tight buffered cable. *TCD* cannot be calculated, but it is assumed that there is a coupling between the 250 µm cable and the outer coating. Furthermore $k > k_f$ is assumed for the coating (yielding increased *TCD*). This statement is also valid for the next cable.

3 mm semi-tight tube: In this cable (Fig. 2c), the *900 µm semi-tight tube* is used as core with 2 additional coatings of aramid and polyolefin [9][††]. This is a typical patch-cord cable.

MEASUREMENT RESULTS

The measurement results can be seen in Table 2 and Fig. 3. First of all, the *250 µm tight buffered* and *loose tube cable* behaved as expected, an indication that there is no effect of the protective coating on the *250 µm tight buffered cables* inside.

Next, the *STOFC* reveals a lower *TCD* as expected. Most likely this is caused by a deviation of the coefficient of thermal expansion. Using a slightly decreased k_j of $-7.6 \cdot 10^{-6}$ K^{-1} in Eq. 1 and 2 delivers a *TCD* of 5.6 ps/km/K. The k_j value in Tab. 1 is not measured but derived from the manufacturing process [4].

The *Non-Kink STFOC* behaved even more unexpected. It was expected to show about the same behavior as *STFOC* without aramid braid, but the measured TCD is significantly lower. We think that there may be two reasons for that: The aramid braid is – contrary to the expectations – not decoupled from the *STFOC* inside and it shows a k of $-12.4 \cdot 10^{-6}$ K^{-1}. Assuming this and considering the interaction of two jackets in Eq. 1 and 2, the resulting *TCD* is -12.3 ps/km/K.

The measurement results of the *PSOF* are within specification [8].

Table 2: TCD Average from 5° C to 45° C

Optical Cable	**TCD [ps/km/K]**	
	Measurement	**Calculation**
250 µm tight buffered	37.5	33.4 to 42.7
STFOC	5.6	11.1
Non-Kink STFOC	-12.2	11.1
PSOF	3.7	< 5.0
Loose tube	42.6	33.4 to 42.7
900 µm semi-tight tube	53.9	> 33.4
3 mm semi-tight tube	128.3	> 33.4

[§]Multi-fiber loose tube, type: 04-4E9/H(ZN)H-E50

[**]Semi-tight tube, type: 01-E9/CH-E9-FE

[††]Single fiber cable with semi-tight tube, type: 01-E9/CWJH-E30

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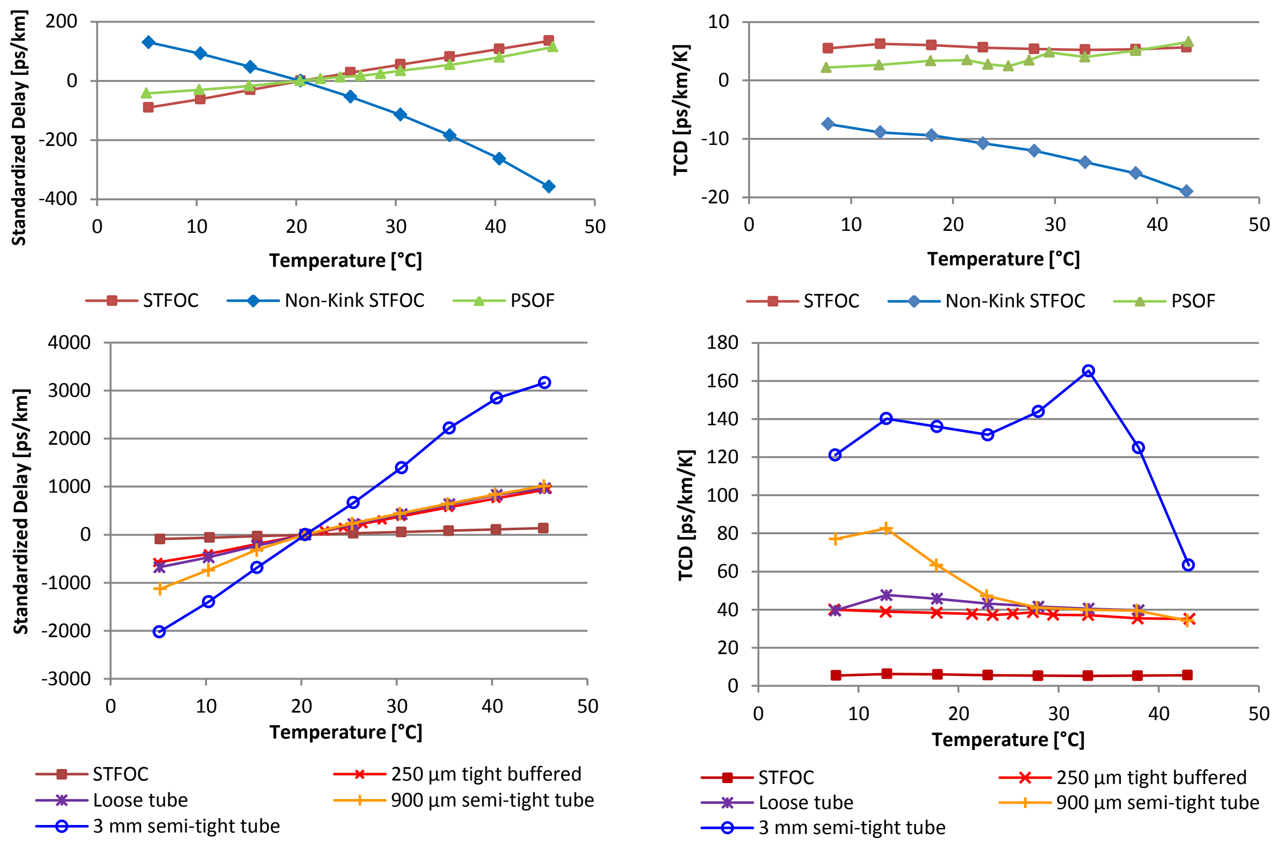

Figure 3: Measurement results of the delay drifts and the corresponding thermal coefficient of delay (TCD).

For the *900 µm semi-tight tube* and the *3 mm semi-tight tube cables* it had been assumed that the inner *250 µm tight buffered cable* is not totally decoupled from the protective coating. The measurements clearly confirmed this assumption over the full temperature range for the *3 mm semi-tight tube cable* and at lower temperatures for the *900 µm semi-tight tube cable* (Fig. 3).

CONCLUSION

An alternative for the *PSOF* from Furukawa has been found. The *STFOC* shows a similarly excellent behavior, while the *Non-Kink STFOC* is the first known cable which shows a negative *TCD*. It has been shown that the coating of a real *loose tube cable* does not affect the TCD of the inner *250 µm tight buffered cable*. In contrast to this, the coatings of the *semi-tight tube cables* do have an effect because they are not totally decoupled. In principle, this effect increases with growing thickness of the coating.

OUTLOOK

In XFEL, it is intended to use the *STFOC* for installation in cable tubes and the *Non-Kink STFOC* on cable trays because this cable type is much more robust. It may be interesting to combine *Non-Kink STFOC* with *900 µm semi-tight tube cables* to get compensating effects for smaller distances were the temperature changes equally along the cable.

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