TEMPERATURE DEPENDENCE OF TWDM NARROW BAND THIN FILM FILTERS FOR THE NEXT GENERATION PON STAGE 2 (NG-PON2)

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Received 30 April 2014; accepted 12 May 2014

1. Introduction

Currently considerable interest has been given to future developments of passive optical networks (PON) satisfying the demands for increasing traffic, higher bandwidth and extended reach [1-3]. Specific wavelength regions for present and future PON technologies are/ should be allocated by the recommendations of International Telecommunication Union (ITU). However, it is necessary to protect present/ future PON signals in optical network units (ONU) at the end of a subscriber from interference from other optical access technologies. To guarantee this, a precise scheme of the wavelength allocation and the implementation of specific wavelength blocking filters are generally recommended. Thin-film interference filters (TFF) are suitable, low-cost and coexisting (i.e. ONU-independent) candidates [4, 5]. In [3] future hybrid time-division/wavelength division multiplexing PONs (TWDM) was designed. In TWDM-PON each wavelength is shared between several optical network units, that use time division multiplexing and multiple access mechanisms.This network can coexist with current 10 Gbit PON when ONUs are provided with narrow-band spectral filters filtering specific signals at wavelengths not being standardized by ITU so far but predicted for this kind of networks [3]. This kind of TWDM network is designed for TWDM downstream being of dense division WDM type (DWDM) with the channel spacing of 0.8 nm (channels of the central wavelengths at 1606.6 nm, 1605.74 nm, 1604.88 nm, 1602.31 nm [6]) or of the coarse division WDM (CWDM) with the channel spacing of 10 nm (channels of the central wavelengths at 1535 nm, 1525 nm, 1515 nm, 1505 nm). For this type of coexisting networks, a thin-film filter was designed in [3] that could operate for all above-mentioned channels of TWDM network for different ONUs when used at different angles of incidence. However this design presumes ideal thin films of the multilayer structure of the band-pass filter, i.e. homogeneous layers with parallel and smooth interfaces made of homogeneous materials which properties are stable and not influenced by the ambient. Nevertheless there are a lot of non-ideal properties like an interface roughness, material and layer thickness inhomogeneities, which negatively affect transfer characteristics of TFFs and can cause signal interferences leading to crosstalks or even channel switching.

This paper numerical studies the influence of non-idealities of refractive indices of materials entering the TFF structures on the transmittance of narrow band-pass TFFs. The influence of temperature of ambient on TFF’s transfer characteristics designed for DWDM and CWDM is under study.

2. Results and discussion

The transfer characteristics of a TFF, e.g. transmittance are substantially influenced by optical properties of materials used for the structure, namely by the refractive index and the extinction coefficient as the real and the imaginary parts of the complex refractive index of a material. As the complex refractive index is directly changed with density and density normally varies inversely with temperature, is not surprising that refractive index varies inversely with temperature [7]. Hence the change of temperature has influence on optical properties of a material. The change of the refractive index with temperature is defined by the thermo-optical coefficient *dn/dT*. The change of the refractive index resp. the extinction coefficient is different for each material. In this paper transmittances of TFFs consisting of three types of materials as fused silica, SiO_2 (silicon dioxide), a-Si (amorphous silica) are numerically studied. The refractive index variation depending on the temperature is shown in Tab. 1 [8,9]. In the table one can see that the most significant influence of temperature on the refractive index of a-Si occurs. On the other hand the refractive index of fused silica is not significantly temperature sensitive. The extinction coefficients of these materials are negligible in the spectral region for which TFFs are designed [10]. The values of the refractive indices at the room temperature were taken from [10].

Tab. 1. *The refractive index variation depending on the temperature [8, 9].*

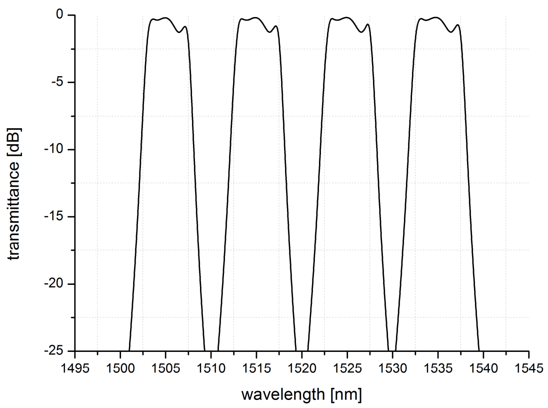
material	fused silica	a-Si	SiO_2
n (@1550 nm)	1.44	3.48	1.46
dn/dT ($*10^{-4}$ K^{-1})	0.0005	2.3	0.1

TFF filters for DWDM and CWDM in future PONs are designed according to the following formula

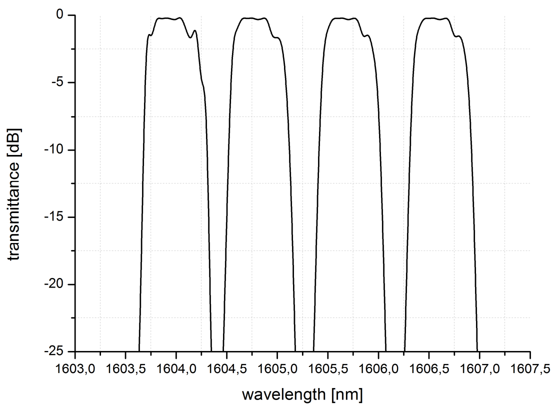
$$\text{ambient}/((LH)^{m_1}\ X\ (HL)^{m_2}\ H)^{n}/\text{substrate}\ [6].$$

In this structure the L- and X-layer means a layer with low refractive index, H means a layer with high refractive index. The material of the L- and X-Layer was simulated to be SiO_2 (silicon dioxide) and material of H-layer was selected to be a-Si (amorphous silicon) [6,10]. As the substrate fused silica was selected and air was considered as the ambient. The X-layer has a larger thickness in the design as the L-layer. For the simulations the transfer matrix method was used according to the theory in [11, 12].

The spectrum of TWDM filters where design presumes ideal thin films of the multilayer structure are depicted in Fig. 1. This figure shows spectrum of four channels of channels with both cases of spacing (10 nm and 0.8 nm).



a)



b)

Fig.1: *Spectrum of four TWDM downstream filters with a) CWDM and b) DWDM spacing.*

For the DWDM scheme the thickness of the L-layer (H-layer) was 230 nm (160 nm). The thickness of the X-layer was of 458 nm. The parameter n = 5 and m_1 = 5, m_2 = 4. The results are illustrated in Fig. 2 where the transmittance of the channel at 1606.6 nm is depicted. It can be seen that even if the temperature influence on the filter contrast factor is negligible the significant changes of the TFF's central wavelength position are important. With the variations of temperature the central wavelength of the channel is changed. If the temperature drops from the room temperature 20°C up to 10°C the central wavelength is shifted so much that even the switching to the second channel with the central wavelength of 1605.74 nm occurs. The switching to the completely different channel is highly undesirable. The same situation occurs at the temperature of 0°C. From these numerical studies it implies that the temperature protection is highly necessary for TFFs used in this type of networks.

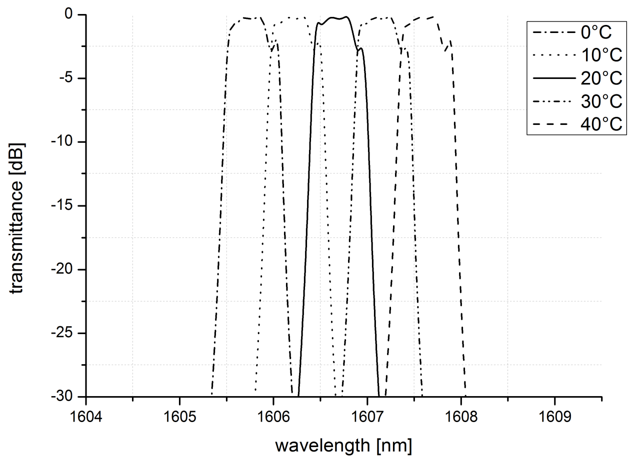


Fig.2: *Temperature dependence of filter transmittance for DWDM division network.*

In the case of CWDM division the channel spacing is 10 nm. The in the above formula the layer thickness of the L-layer should be of 250 nm, of the H-layer 130 nm and of the X-layer 489 nm. The parameter n = 4 and m_1 = 3, m_2 = 2. The results can be seen in Fig. 3 for the channel at the wavelength of 1535 nm. From Fig.3 it can be observed that the influence of the temperature on the filter transmittance is not as significant as in the case of DWDM division. If the temperature decreases up to 0°C the wavelength shift of the filter spectrum is about 1 nm what for this filter of this kind is any critical value. We can deduce that real temperature changes do not cause switching to another CWDM channel and no special measures concerning temperature stability must be done.

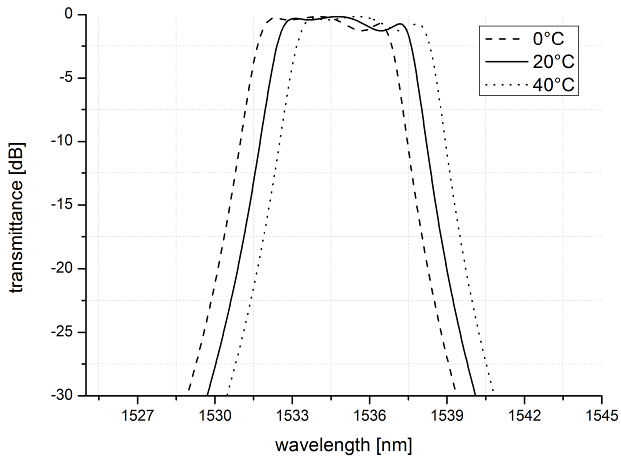


Fig.3: *Temperature dependence of filter for CWDM division network.*

Wavelength shift of filters spectra is for both cases at temperature 0°C comparable and its approximately 1 nm. The difference is that the narrow band DWDM channels are more sensitive to wavelength shift because a small change of temperature will cause that part of channel intensity is not filtered resp. is filtered energy from adjacent channel. The temperature effect is not so important for CWDM channels since the wavelength shift ~ 1 nm do not cause so significant channel overlays.

3. Conclusion

In this paper we present influence of the temperature on the transfer characteristics of thin film narrow-band interference filters. Is shown that for filters with CWDM channel spacing the temperature dependence is not significant but for filters with DWDM channel spacing the temperature is a very important parameter. Because narrow-band thin film filters are more sensitive to non-ideal properties (especially temperature in this study) it is recommended to propose new network elements to compensate the non-ideal properties.

Acknowledgement

This work was partly supported by the Slovak Grant Agency under the project VEGA 2/0076/12, VEGA 1/1271/12 and by the Slovak Research and Development Agency under the projects APVV-0888-11 and APVV-0025-12.

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