Analysis on long-term reliability of polymer optical fiber (POF)

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ABSTRACT

The lifetime of POF has been major concern among those who actually utilize POF for lighting, decorating, sensing, and data communication. As regards home networking, special emphasis is placed on long-term reliability. We, as one of POF manufacturers, presented high-temperature accelerated test data, however, it is not simple to presume the lifetime of POF installed under actual circumstances. The strenuous study on reliability of POF has been done at BAM and they presented interesting results so far. Since we as well keep studying on the lifetime of POF, we report the results from our experiment in presuming the lifetime of POF under such circumstance as in-house cabling.

1. INTRODUCTION

POFs have been used in the field of short-haul data communication such as automobile, audio equipment and factory automation and so on. Recently with the expansion of the high-speed Internet and digital consumer electronics applications, the demand for making high-speed movie transfer between personal computers and those consumer electronics devices like video and TV in home by connecting them has been rapidly rising. Moreover home networks, which enable exchange information and pictures between rooms are about to realize. In case of utilizing POFs as infrastructure for home networks, the long-term reliability should be required as residences are commonly used for long years. Therefore it is the most important issue to estimate the lifetime of POFs. This report introduces one approach to estimate the lifetime by measuring transmission loss under various high temperature conditions.

2. THEORY

Polymers gradually change their own characteristics, over time. These changes are caused by chemical reactions, and then in the most cases materials degrade by these irreversible reactions. These reactions are expressed as a function of temperature and time on the basis of the rates and chemical reactions law. The degradation is considered to be a change of material characteristics caused by a change of molecular structure after chemical reactions. As the reactions are assumed to be first-order reactions, its rate law concerned with the degradation parameter P is presented by below equations.

$$\frac{dP}{dt} = -kP \qquad (1)$$

Where t and k are time and the rate parameter respectively.

$$k = A\exp\left(-\frac{E}{RT}\right) \qquad (2)$$

The parameters A, E, R and T are defined as the frequency, the activation energy, the gas constant and the absolute temperature, respectively.
On the assumption that the characteristic parameter varies from P_0 to P while the time varies from 0 to t, the equation (1) is integrated and obtains following eq. (3).

$$\ln t = \ln\left\{-\frac{1}{A}\ln\left(\frac{P}{P_0}\right)\right\} + \frac{E}{RT} \qquad (3)$$

From eq. (3), a plot of In t against 1/T gives a straight line and the slope of the line gives E/R. This kind of graph is called the Arrhenius plot.

Around the room temperature, the speed of degradation is too slow to observe. Therefore the lifetime of materials in their used temperature is generally estimated by the measurement in higher temperature and shorter time.

3. EXPERIMENTAL PROCEDURE AND RESULTS

3-1. Experimental procedure

We prepared some POFs of which cores are composed of polymethyl methacrylate (PMMA). The spectral attenuations of them have been investigated under several temperature conditions. Fig. 1 shows the attenuation of the POFs jacketed with polyethylene after 85℃ aging test. It is observed that the degradation has progressed with aging time. Especially, shorter wavelength region has varied faster and the slope from ultra-violet absorption influences linearly to visual region.

However less influence of the degradation appears at wavelength 650nm that is mainly used for communication usage. Therefore the degradation behavior at 650nm is estimated by investigating the changes at wavelength 440nm that can be expected faster variations.

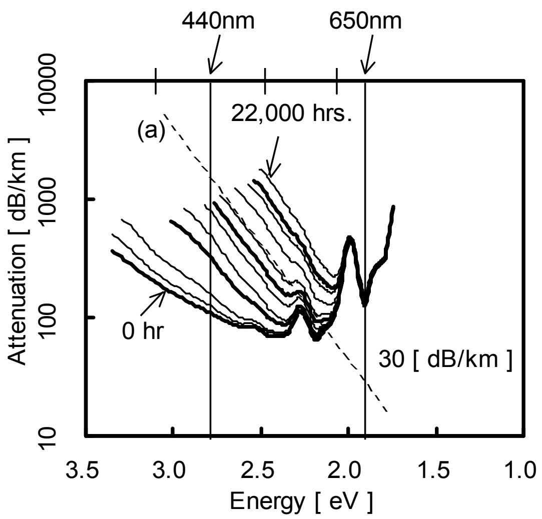

Fig.1 The attenuation during 85℃ aging

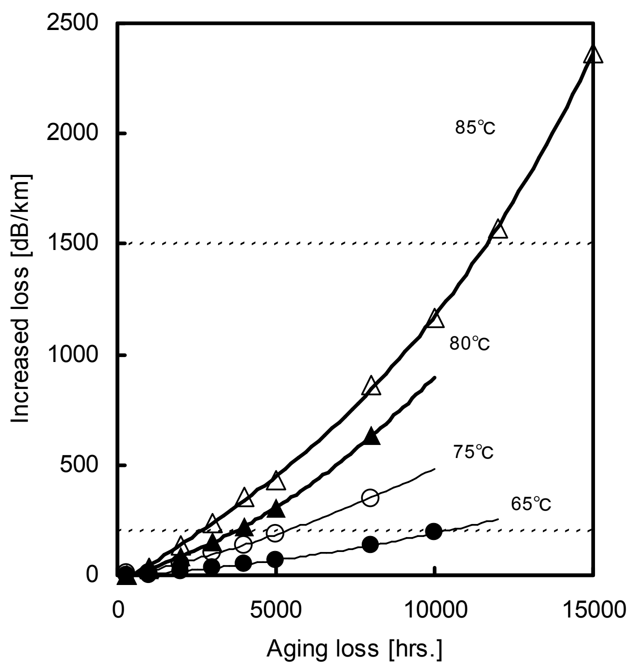

Fig.2 The increased loss at wavelength 440nm

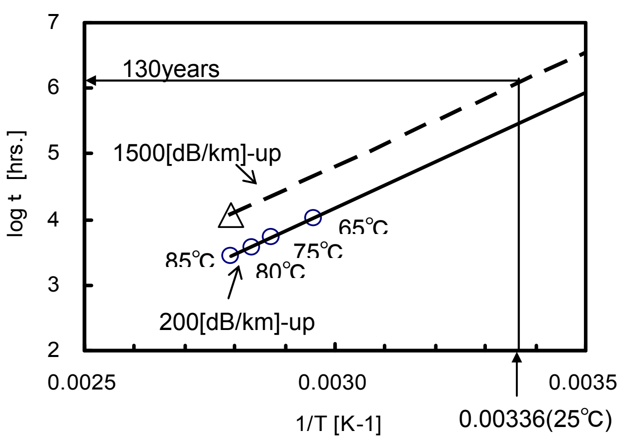

Fig.3 The Arrhenius plot

Fig.2 shows the increased losses with aging time under several temperature conditions. By plotting the time at which the loss reach at 200dB/km, shown as broken line in Fig2, as a function of temperature, the Arrhenius plots can be obtained and drawn the solid line by the method of least squares in fig.3.

From fig.3, these plots show a straight line, and then it can be considered that the degradation might be caused by the reaction of Arrhenius type. The activation energy is calculated 67[kJ/mol] from the slope.

From fig.1 under 85℃ aging condition, assuming that the end of the POF's life is the time that the increased loss at 650nm becomes 30[dB/km], corresponding increased loss at 440nm appeared to be 1500[dB/km]. In case of the lower temperature aging tests, measurement time takes too long to obtain the same data. As the cause of the each degradation is considered to be the same as that of 85℃ aging test, we can draw the parallel broken line to the solid line from the point of 1500[dB/km] at 85℃, and extrapolate to room temperature. If a POF are supposed to be used in rooms at an average temperature of 25℃(1/T=0.00336) a year, the lifetime of the POF is estimated for about 130 years, and it is for about 80 years at an average temperature of 30℃ (1/T=0.00330) a year. The measurement data mentioned above is one example with little dispersion.

3-2. The aging results under dry conditions

Table 1 shows the 200[dB/km]-up aging times of POFs covered with polyethylene under dry conditions from 65℃ to 90℃ at wavelength 440nm. These data include some kind of POFs produced in different lot. And fig. 4 shows the Arrhenius plots of the data in Table 1 and indicates some dispersion. But the same tendency mentioned above can be clearly observed in this figure. Generally it is said that about ±10% dispersion are measured in aging tests. Therefore it can be considered that these dispersions are permissible range.

Table 1. Aging time until 200[dB/km] increased loss under dry condition
(POFs covered with polyethylene)

Sample No.	T [℃]	K	1/K	t [hrs.]	log t
1	90	363	0.00275	2100	3.32
2	90	363	0.00275	1600	3.20
3	90	363	0.00275	1400	3.15
4	85	358	0.00279	2100	3.32
5	85	358	0.00279	2500	3.40
6	85	358	0.00279	2500	3.40
7	85	358	0.00279	2300	3.36
8	80	353	0.00283	4500	3.65
9	75	348	0.00287	3600	3.56
10	75	348	0.00287	3400	3.53
11	75	348	0.00287	5000	3.70
12	70	343	0.00292	11000	4.04
13	65	338	0.00296	10000	4.00
14	65	338	0.00296	13000	4.11

Then the activation energy can be estimated approximately from 65[kJ/mol] to 85[kJ/mol].

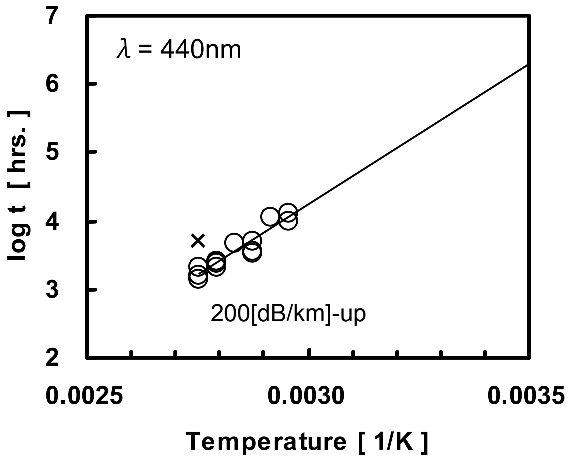

Fig.4 The Arrhenius plot under dry condition
(POFs covered with polyethylene)

3-3. The aging test results under high humidity conditions

Table 2 shows the 200[dB/km]-up aging times of POFs covered with polyethylene under 95% relative humidity conditions from 65℃ to 75℃ at wavelength 440nm. And fig.5 is the Arrhenius plots of the data in table 2, and the activation energy can be calculated 74[kJ/mol] from the slope of the line drawn by the method of least squares. From this result, when we estimate the lifetime of POFs used as a home network, it seems that only little difference exists between dry condition and high humidity condition. But now we also insist that these results mentioned above are presented the potential of POFs, and if the POF is supposed to be used under mild conditions like in home, the long lifetime for about 100 years can be expected.

Table 2. Aging time until 200[dB/km] increased loss under 95%RH condition
(POFs covered with polyethylene)

Sample No.	T [℃]	K	1/K	t [hrs.]	log t
15	75	348	0.002874	6000	3.78
16	75	348	0.002874	6200	3.79
17	70	343	0.002915	8500	3.93
18	70	343	0.002915	7600	3.88
19	70	343	0.002915	7400	3.87
20	65	338	0.002959	14000	4.15
21	65	338	0.002959	12000	4.08

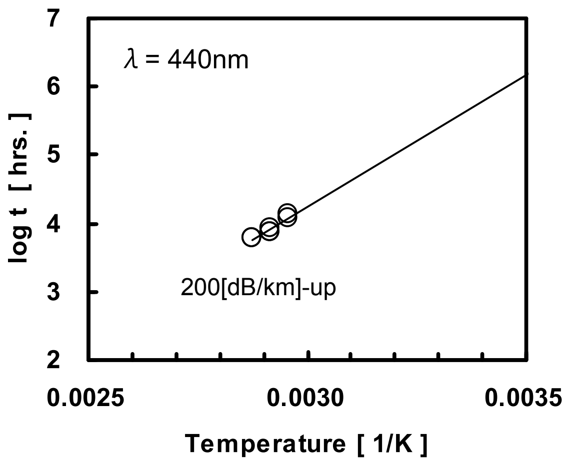

Fig.5 The Arrhenius plot under 95%RH condition
(POFs covered with polyethylene)

3-4. The aging test results of bare POFs

In addition, the aging tests of bare POFs have been measured by almost the same conditions as those covered with polyethylene. Those Arrhenius plots are shown in fig.6 under dry conditions and fig.7 fewer than 95% relative humidity conditions. From the slopes of these data, the activation energy under dry conditions is calculated as

77[kJ/mol] and one fewer than 95% relative humidity conditions is 81[kJ/mol]. As these values belong to the same range as the POFs covered with polyethylene. These results suggest that the cause of the bare POF's degradation is similar to those covered with polyethylene.

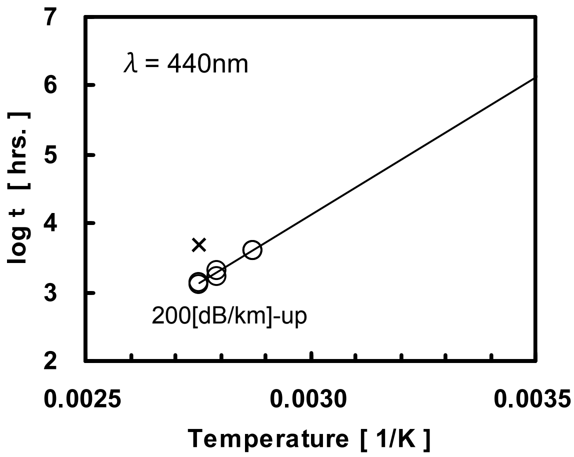

Fig.6 The Arrhenius plot under dry condition (bare POFs)

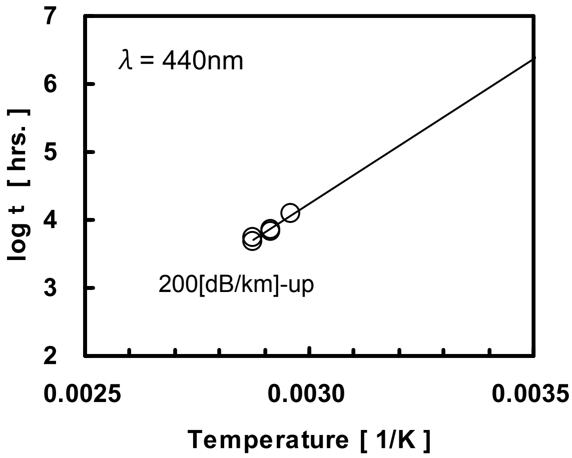

Fig.7 The Arrhenius plot under 95%RH condition (bare POFs)

We also measured under nitrogen atmosphere condition at 90 ℃. The results are the cross-points plotted in fig.4 and fig.6. The delay of the degradation speed is observed. The difference suggests the cause of the POF's degradation might relate to oxidation of PMMA.

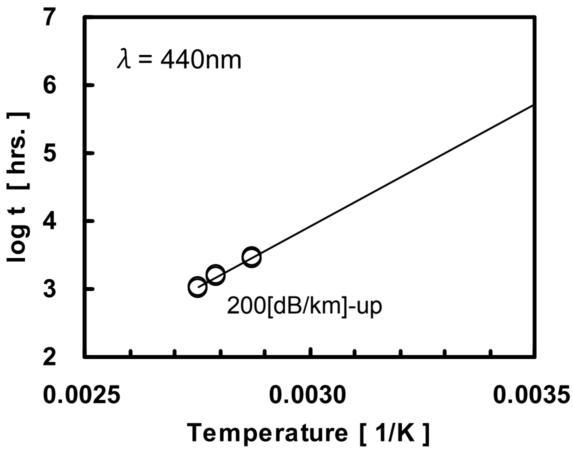

Fig.8 The Arrhenius plot under dry condition (bare POFs)

Fig.8 shows the Arrhenius plots of a PMMA-POF produced by changing a initiator and a chain-transfer reagent and using a different polymerization process. The activation energy of this POF is 69[kJ/mol]. The degradation process in this case is supposed to be the same, those residues in core materials may not influence to the degradation process.

4.CONCLUSION

Lifetime of PMMA core POF has been estimated through accelerated condition-aging tests. Arrhenius type behavior is presumed for estimation. The estimation suggests, in room temperature, the lifetime is approximately over 100 years, where in real environment more complex causes, such as chemical conditions, mechanical stress or exposure to the high-energy radiation may influence to the lifetime.

5.REFERENCE

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