Technical University of Denmark

Viscoelastic limit of polymer optical fibers: characterization of the dynamic response

Stefani, Alessio ; Yuan, Scott Wu; Andresen, S.; Bang, Ole

Published in:
Proceedings of the 20th International Conference on Polymer Optical Fibers

Publication date:
2011

VISCOELASTIC LIMIT OF POLYMER OPTICAL FIBERS: CHARACTERIZATION OF THE DYNAMIC RESPONSE

A. Stefani (1), W. Yuan (1), S. Andresen (2), O. Bang (1)

1: DTU Fotonik, Department of Photonics Engineering, Technical University of Denmark, 2800 Kgs.Lyngby, Denmark
2: Brüel & Kjær Sound and Vibration Measurements A/S, 2850 Nærum, Denmark

Corresponding author: alste@fotonik.dtu.dk

Abstract: Characterization of polymer optical fibers (POFs) in terms of dynamic behavior is important for many sensors applications for which this type of fibers offers big advantages. We report measurements of the Young's modulus on microstructured and step index polymer optical fibers and their comparison with silica fiber for a frequency range up to 300 Hz. In this range a constant modulus has been measured, allowing the use of polymer fibers for applications like Bragg grating based accelerometers.

Key words: Polymer optical fibers, Dynamic response, Fiber sensors.

1. Introduction

One of the material properties that makes POFs appealing for sensing applications, together with their large elastic limit, is their low Young's modulus. In fact, polymer fibers have a Young's modulus that is usually more than one order of magnitude lower compared to that of silica fibers [1]. This can improve the sensitivity of strain based sensors, since the same excitation (for example, stress) would produce a response inversely proportional to the Young's modulus. On the other hand polymers are viscoelastic materials. Viscoelastic materials do not have a constant response to strain/stress with frequency due to molecular rearrangement, which dissipates part of the accumulated energy as in a plastic deformation [2-5]. Moreover it is well known that for bulk polymers this behavior occurs at really low frequencies (often even less than 1 Hz) [2]. This material property seems to exclude polymer optical fibers from all those sensing applications in which the frequency response of the sensor is one of the main characteristics, e.g. accelerometers, microphones and sensors for fast vibrations detection. In order to fully understand and characterize the viscoelastic properties of polymer optical fibers and exploit the favorable regimes when making POF based sensors, measurements of the dynamic Young's modulus and of the recovery time are necessary. There has been some studies on dynamic behavior of polymer optical fibers [6-7], but without investigating the frequency dependent Young's modulus.

We report on dynamical characterization of polymer optical fibers, including both step index and microstructured POF.

2. Dynamic response

2.1. Experimental set-up

The experimental set-up can be seen in Fig. 1. It basically consists of a shaker whose frequency-tunable displacement can be induced by applying a certain amount of current, of a reference accelerometer placed on top of the shaker (it is used to make sure that the load due to the fiber doesn't influence the shaker produced displacement), and of a force gauge to measure the force the fiber undergoes. The fiber is fixed by means of two mechanical clamps on one side to the shaker and on the other to the force gauge.

This measurement is different from typical dynamic mechanic analysis [2] in which a known force is applied and the elongation is measured.

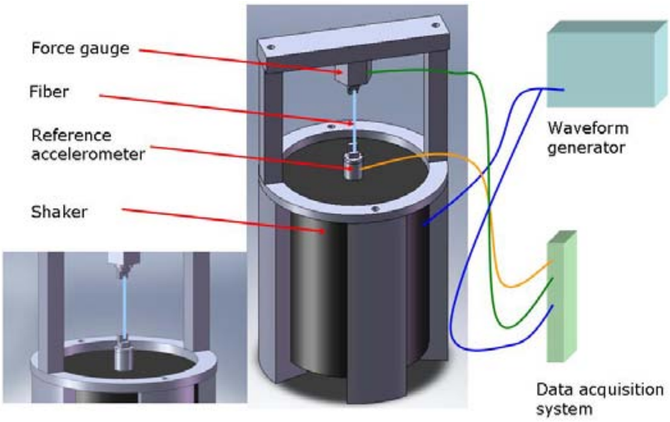

Fig. 1: Experimental set-up. The fiber is placed between a shaker(that produces a desired elongation) and a force gauge.

2.3. Results

Two different measurements have been performed. The first one is a measurement of the Young's modulus as function of frequency. A periodic excitation was applied to the fiber. The elongation was known and the force was measured. From this data the frequency dependent spring constant was measured. The result for a micro-structured polymer optical fiber (mPOF) with 3 rings of holes of 6 µm and pitch 3 µm is shown in Fig. 2. The system showed the first mechanical resonance around 600 Hz, so the useful measurement range is limited to just over 100 Hz. Moreover the low frequencies limit, given by the measurement system, is around 5 Hz. In this range it is possible to see that the response is quite constant.

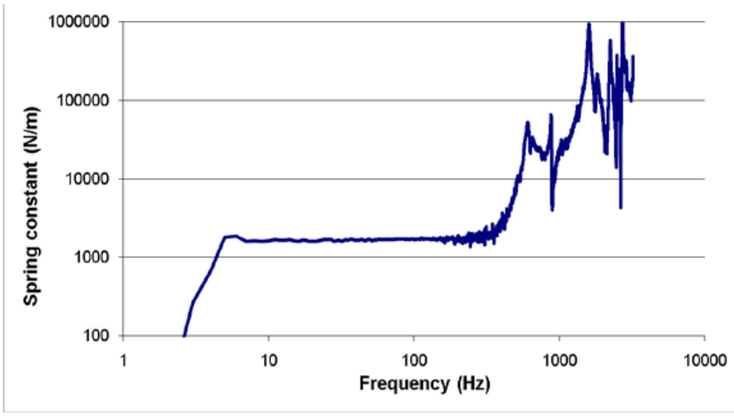

Fig. 2: mPOF strain response.

The same response has been measured for two other fibers: a step index POF and a standard SMF28 silica fiber. In Fig. 3 it's possible to see the comparison of the Young's modulus (calculated from the spring constant knowing the fibers length and diameter). As expected the silica fiber has a modulus of over one order of magnitude higher than both polymer fibers. From the frequency point of view all the fibers show a flat response in the region of interest 10 to 100 Hz.

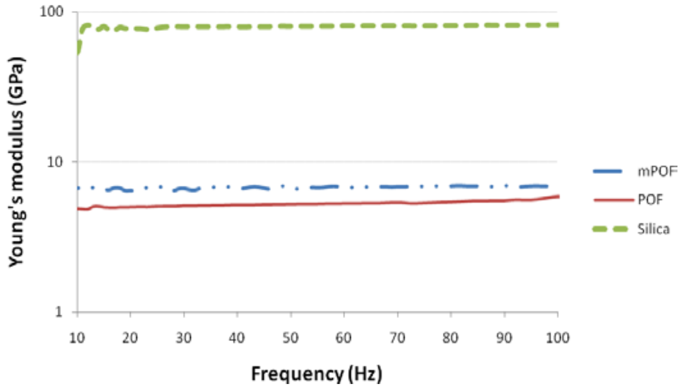

Fig. 3: Measured Young's modulus as function of frequency for a step index POF, a microstructured POF, and a silica SMF28 fiber.

A second measurement was also performed. A sudden elongation was applied to the fiber (in this case the mPOF) and the time response of the fiber was then measured to observe the relaxation time. The fiber was then released from the strain to monitor the recovery behavior. The result is shown in Fig. 4.

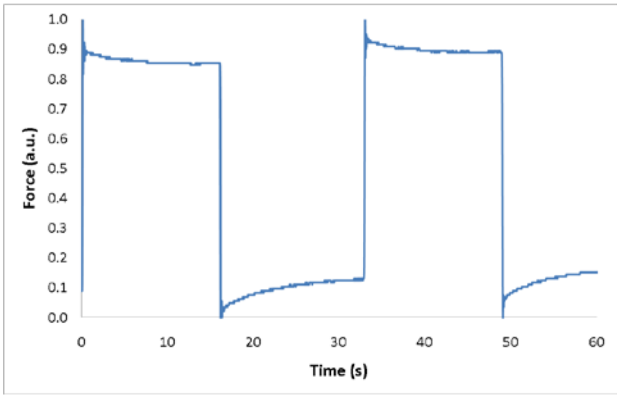

Fig. 4: Step response for the mPOF

As expected the fiber releases some of the force, in the stretching cycle and re-tension when being released, thus showing the typical viscoelastic behavior.

3. POF based dynamic sensor

The POFs have, subsequently, been used to produce a fiber Bragg grating based accelerometer. The grating elongation and consequent wavelength shift proportional to the acceleration was produced by a fork that acts as transducer. In characterizing the accelerometer, the frequency response was measured. The result (where the fiber used is the step index POF) is shown in Fig. 5. A flat response for frequencies up to 1.1 kHz with a sensitivity of 20 pm/g and a resonance frequency around 3 kHz are the main characteristics of the accelerometer. This result shows how there are no problems with the frequency dependent response of the polymer, at least for this application.

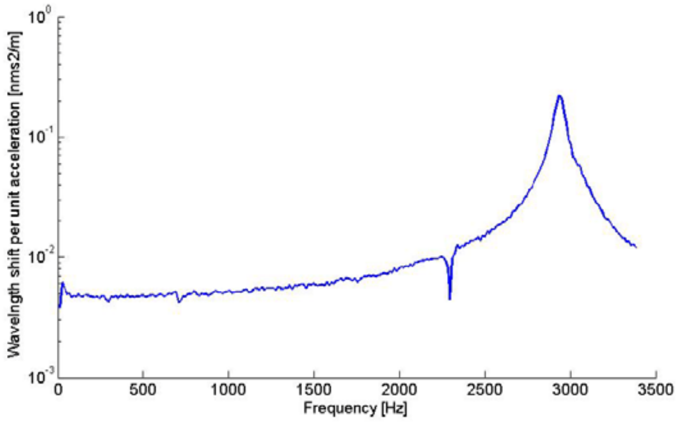

Fig. 5: Frequency response of the polymer optical fiber Bragg grating based accelerometer.

3. Conclusions

In conclusion we reported on characterization of dynamic behavior of polymer optical fibers. In particular we showed a flat Young's modulus for frequencies up to 100 Hz. We also demonstrate an application of these fibers in a fiber Bragg grating based accelerometer.

Acknowledgements

We would like to acknowledge support from the Danish National Advanced Technology Foundation.

References

[1] M.C.J. Large, L. Poladian, G.W. Barton, M.A. van Eijkelenborg, *" Microstructured polymer optical fibers"*(New York: Springer, 2007).

[2] K.P. Menard, *"Dynamic mechanical analysis: a practical introduction"* (CRC PressI , 1999).

[3] D. Roylance, *"Engineering viscoelasticity"* (Cambridge, Ma: MIT Press, 2001).

[4] J. Roesler, H. Herders, M. Baeker, *"Mechanical behavior of polymers" in "Mechanical behavior of engineering materials"*, (Springer, 2007).

[5] J.J. Benbow, F.N. Cogswell, M.M. Cross, *"On the dynamic response of viscoelastic fluids"*, Rheol Acta, 15, 5 , 231-237, 1976.

[6] M.C.J. Large, J. Moran, L. Ye, *"The role of viscoelastic properties in strain testing using microstructured polymer optical fibres (mPOF)"*, Meas. Sci. Technol., 20, 3, 034014, 2009.

[7] C. Jiang, M.G. Kuzyk, J.L. Ding, W.E. Johns, D.J. Welker, *"Fabrication and mechanical behavior of dye-doped polymer optical fiber"*, J. Appl. Phys, 92, 1, 4-12, 2002.