Grating couplers in polymer with a thin Si_3N_4 layer embeded

Linghua Wang[*a,b,d], Yanlu Li[a,d], Marco Garcia Porcel[a,d], Diedrik Vermeulen[a,d], Xiuyou Han[b], Jinyan Wang[c], Xigao Jian[c], Mingshan Zhao[b] and Geert Morthier[a,d]
[a]Photonics Research Group, INTEC-Department, Ghent University-IMEC, Ghent B-9000, Belgium
[b]School of Physics and Optoelectronic Technology, Dalian University of Technology, Dalian, 116023, China
[c]Department of Polymer Science& Materials, Dalian University of Technology, Dalian, 116023, China
[d]Center for Nano- and Biophotonics (NB-Photonics), Ghent University, Ghent B-9000, Belgium

ABSTRACT

Polymer has been considered to be an ideal material option for integrated photonics devices. To measure these devices, normally the route of horizontal coupling is chosen to couple the light into or out of the polymer waveguide. Due to the relatively low refractive index, implementing the surface grating coupler in this material system remains to be a challenge. In this paper, we present a polymer based surface grating coupler. Rather than expensive CMOS fabrication, the device is fabricated through a simple and fast UV based soft imprint technique utilizing self-developed low loss polymer material. The coupling efficiency is enhanced by embedding a thin Si_3N_4 layer between the waveguide core and under cladding layer. Around -19.8dB insertion loss from single-mode fiber (SMF) to single-mode fiber is obtained for a straight waveguide with grating coupler at each end. If collected with multi-mode fiber (MMF), it can be reduced to around -17.3dB. The 3dB bandwidth is 32nm centered at 1550nm. The proposed surface grating coupler and its easy fabrication method would be attractive for practical applications.

Keywords: polymer waveguide, surface grating coupler, inverted-rib waveguide, coupling efficiency

1. INTRODUCTION

Recently, biological and chemical sensors have attracted lots of attention due to their vast applications in the fields of food safety and environmental monitoring, point-of-care diagnostics, drug discovery and so on. Among these different types of sensors, planar integrated photonic biosensors own distinct advantages. By using photonic biosensors as transducer and detecting their output optical signal, label-free and real time monitoring of the dynamics of molecules' reactions is made possible. The sensor can be designed as a planar cavity structure, a ring or disk resonator for example, to reduce the footprint but greatly enhance the sensitivity [1, 2]. Fabricating photonic biosensors with mature techniques such as CMOS based processes or novel nanoimprint lithography further reduces the chip cost with high volume production [3, 4].

Besides the advantages mentioned above, compact sized photonic biosensors with different functionalized surfaces can be accommodated onto a single chip, which makes multiplexed sensing possible. This has been realized within the SOI platform through the well known surface grating coupler [5]. The output signals from different channels during sensing are vertically coupled into free space and collected by an infrared camera. Besides the SOI platform, polymer has also been considered to be an ideal material platform for photonic biosensors, with the advantages such as extremely low cost, biocompatibility and so on [6, 7]. The polymer based photonic biosensors can perform as well as their counterparts in SOI with similar design structures [8-11]. However, a surface grating coupler is difficult to be implemented in this material platform because of the low refractive index contrast [12, 13], which limits the application of photonic biosensors based on polymer for multiplexed sensing. In contrast, the route of horizontal coupling is usually chosen in order to couple the light into or out of the polymer waveguide, in which case the requirement for good waveguide facets is high [14]. Another problem for horizontal coupling is small tolerance on the alignment. For single mode polymer waveguides, the measured power could fall dramatically with a few micrometers fiber drift. In order to circumvent these problems, we propose a grating coupler built on the polymer platform. Rather than expensive CMOS fabrication, the

* linghua.wang@intec.ugent.be; phone +32 - 9 - 264 3318; fax +32-9-264 3593;

Organic Photonic Materials and Devices XIV,
Edited by Christopher Tabor, François Kajzar, Toshikuni Kaino, Yasuhiro Koike,
Proc. of SPIE Vol. 8258, 825817 · © 2012 SPIE · CCC code: 0277-786X/12/$18 · doi: 10.1117/12.908553

Downloaded from SPIE Digital Library on 07 Apr 2012 to 130.237.22.49. Terms of Use: http://spiedl.org/terms

device is fabricated through a simple UV based soft imprint technique utilizing self-developed low loss polymer material. The coupling efficiency is enhanced by embedding a thin Si_3N_4 layer between the waveguide core and under cladding layer. Around -19.8dB insertion loss (fiber to fiber) is obtained for a straight waveguide with grating couplers at each end. By calculation, the proposed grating coupler has a coupling efficiency of around 12%. The 3dB bandwidth is 32nm centered at 1550nm.

2. PROPOSED STRUCTURE AND SIMULATION

As mentioned before, the fundamental reason why the surface grating couplers cannot obtain a high coupling efficiency is the low refractive index of the polymer. The perturbation from the grating structures on the polymer waveguide surface has a limited influence on the waveguide mode, such that most of the light transmits directly through the waveguide instead of being diffracted out of the plane. Therefore the upward radiated power can be increased if this perturbation is strengthened. The field profile must also be optimized in order to increase the coupling to the fiber.

The proposed structure is depicted in Fig. 1. The grating pattern is fabricated on the under cladding layer, which sits on top of the Si substrate. A high refractive index layer, Si_3N_4 in our case, is selectively deposited on the grating and then embedded between the under cladding and waveguide core layer. The excess part of the Si_3N_4 layer is removed from the waveguide to prevent additional loss.

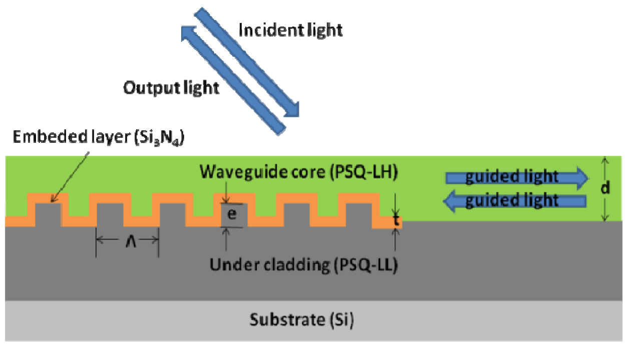
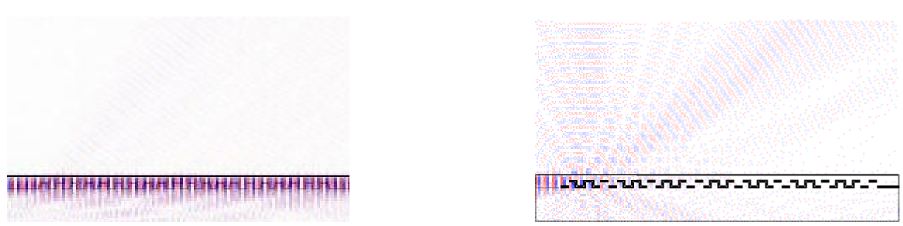


Fig. 1 The proposed polymer based surface grating coupler

The simulation is carried out with the combination of CAMFR and FDTD (Finite-time-domain-difference). Parameters such as thickness of waveguide core, thickness of Si_3N_4 layer, grating height, grating period and so on are optimized to obtain suitable coupling angle, higher upward power, ideal diffracted field profile and thus higher coupling efficiency with the fiber. The electric field plot with and without the embedded high index Si_3N_4 layer are shown in Fig. 2. The used parameters are as follows: thickness of waveguide core d=1.7µm, grating height e=0.7µm, thickness of Si_3N_4 layer t=0.2µm, grating period Λ=1.7µm. It can be clearly seen that after adding the Si_3N_4 layer, the perturbation of the surface grating on the waveguide mode is strongly enhanced, resulting in more upward power with diffraction angle around 43 degree. Besides that, the near field electric field starts exhibiting a quasi Gaussian profile, which is more easily fitted to the field profile of the fiber to have higher coupling efficiency. This is shown in Fig. 3. The spectral response of the grating with the optimized structure is shown in Fig. 4. It shows a maximum coupling efficiency with the single mode fiber of around 19%. Another benefit brought by this structure is polarization selectivity. The TM mode light cannot be coupled into or out of the polymer waveguide as effective as the TE mode light, and only has an efficiency of less than 6%.



(a) (b)

Fig. 2 The electric field plot without (a) and with (b) the embedded high index Si3N4 layer

Downloaded from SPIE Digital Library on 07 Apr 2012 to 130.237.22.49. Terms of Use: http://spiedl.org/terms

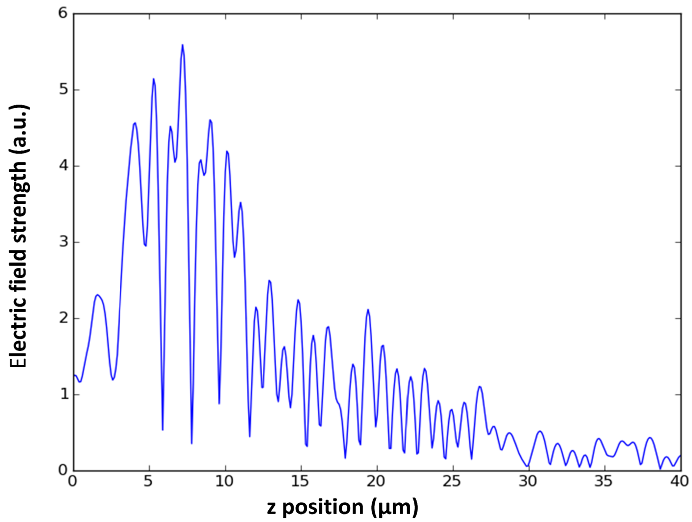


Fig. 3 The near field profile of the proposed grating structure

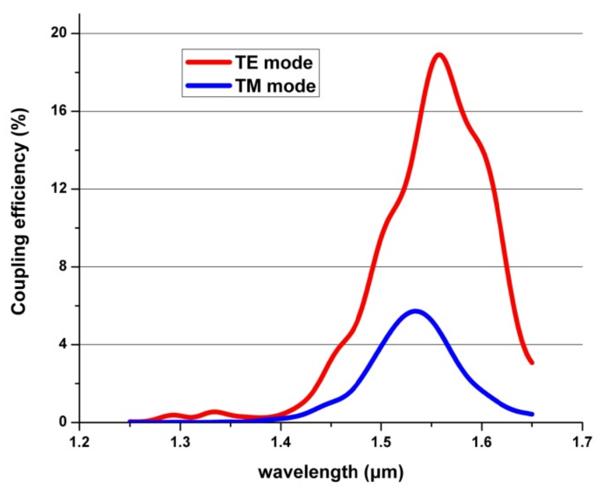


Fig. 4 The spectrum response of the proposed grating structure

3. MATERIALS AND FABRICATION PROCESSES

We developed a simple UV based soft imprint technique to realize the structure proposed above. Compared with the lithography and dry etching method, this technique has been proved to be an efficient way to directly pattern the polymer waveguide and devices. However, this process has certain requirements on the imprinted material. Besides the good optical properties such as low optical loss, low birefringence and high thermal stability, good UV curing property and low viscosity are needed to make it well compatible with the UV based soft imprint technique. The material we used for this work meets the requirements above. Its two components, PSQ-LH with high refractive index (n=1.52) and PSQ-LL with low refractive index (n=1.45), are used as the waveguide core and cladding respectively [15, 16].

The process starts with the fabrication of the patterned mold. The PDMS soft mold is replicated from a master mold on which the grating and waveguide patterns are defined by the contact lithography. The obtained soft mold is then pressed against the under cladding layer which is spin coated on the silicon wafer. After 3min UV light curing with a intensity of

Downloaded from SPIE Digital Library on 07 Apr 2012 to 130.237.22.49. Terms of Use: http://spiedl.org/terms

around 2000mJ/cm^2, the soft mold is peeled from the substrate, leaving the grating and waveguide patterns on the under cladding layer. 2 hours of 180˚C thermal curing is used to fully cure this layer. In order to realize the selectively Si_3N_4 embedded structure, at first the previously obtained sample is deposited with Si_3N_4 through PECVD. This step needs to be optimized because our polymer cannot resist too high temperature (above 200˚C) during deposition. While using too low temperature will be detrimental to this dielectric layer, especially its refractive index will drop dramatically. By experimenting, the deposition temperature was chosen to be 150˚C. Around 17min time was used to achieve the targeted 200nm layer thickness. Rather than dry etching, a simple wet etching method was used to completely remove the Si_3N_4 layer out of the waveguide region, leaving only the grating area covered by the Si_3N_4. After the spin coating and curing of the core layer PSQ-LH, the proposed surface grating coupler structure was realized. The fabrication process is shown in Fig. 5. The microscope and SEM images are shown in Fig. 6a and Fig. 6b.

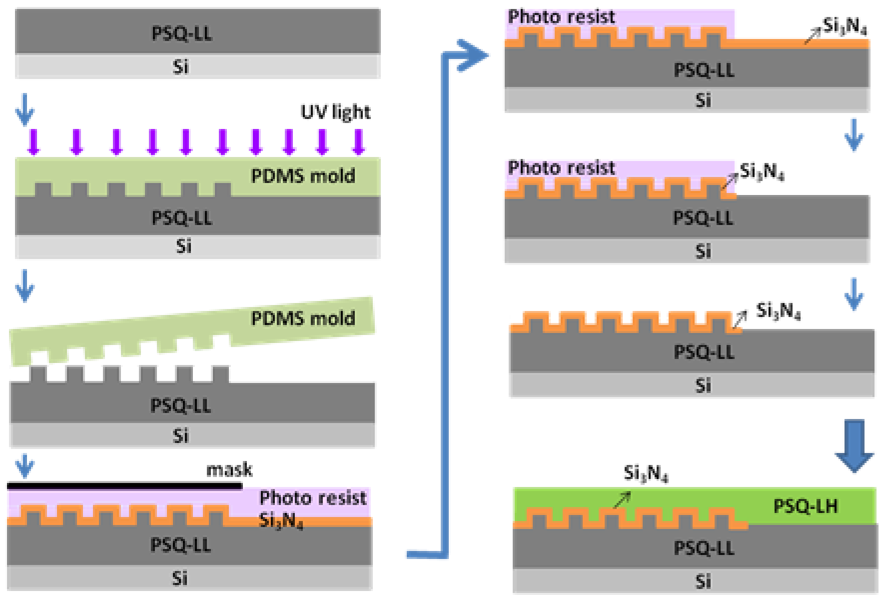
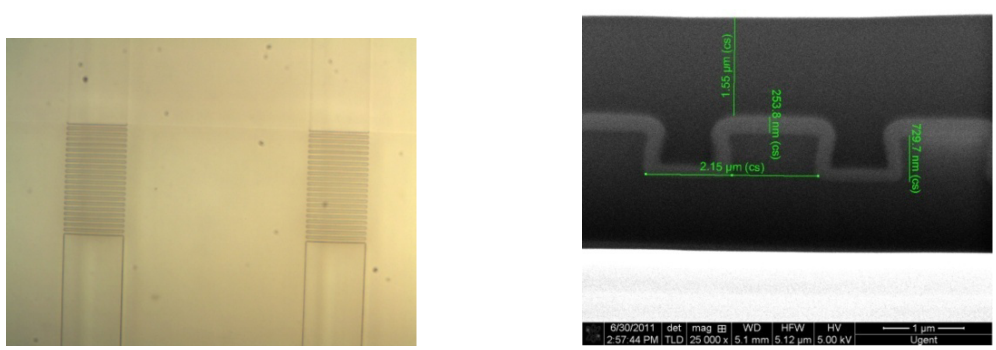


Fig. 5 The fabricating process of UV soft imprint lithography combined with wet etching to realize the proposed structure.



(a) (b)

Fig. 6 The microscope (a) and SEM (b) picture of the fabricated surface grating coupler with Si_3N_4 layer imbedded between the core and under cladding layer.

Downloaded from SPIE Digital Library on 07 Apr 2012 to 130.237.22.49. Terms of Use: http://spiedl.org/terms

4. MEASUREMENT RESULTS

The straight waveguide with two surface grating couplers at each end is measured with vertical setup. A cleaved single mode fiber connected to a tunable laser through the polarization controller was used to launch the light. The light diffracted by the surface grating coupler at the output was collected by a single-mode fiber (SMF) or a multi-mode fiber (MMF), which is connected to a power meter. The measurements result is shown in Fig. 7. The optimal coupling angle was found to be 40˚. Under this measuring angle, around -19.8dB insertion loss (SMF to SMF) is obtained. We measured the straight waveguide loss with the similar inverted-rib structure through Fabry-Perot resonance method before and it was found to be 1.7dB/cm. In this case the length of the straight and tapered waveguide connected two surface grating couplers is 5mm, resulting in an estimated transmitting loss of 0.85dB. The link loss is measured to be 0.42dB at 1550nm wavelength. Thus the coupling efficiency for each surface grating coupler can be determined to be -9.27dB (nearly 12%) conservatively. There are another two factors we still haven't taken into account because they are difficult to be predicted currently. One is the junction loss from the grating coupler to the waveguide and the other is the surface reflection loss. Considering this, the resulting coupling efficiency can be even higher. The 3dB bandwidth is 32nm centered at 1550nm. MMF was also used to receive the output power. Because of the large aperture of the MMF, the total insertion loss (SMF to MMF) was reduced by 2.5dB, which is -17.3dB.

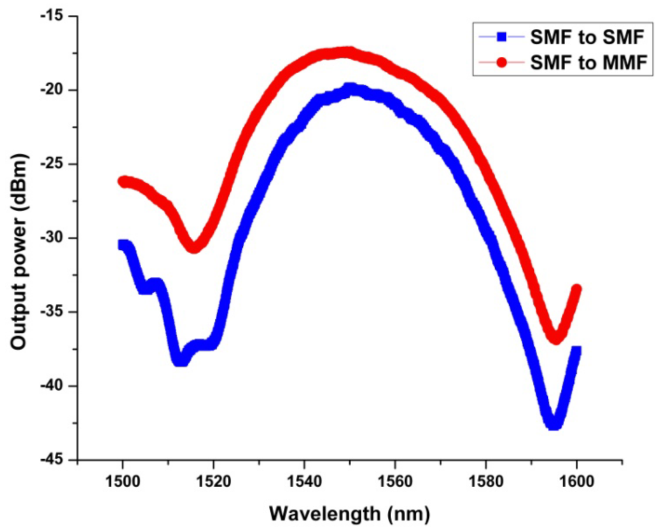


Fig. 7 The measured fiber to fiber transmission of the straight waveguide with two grating couplers at each end.

In order to find out that how the energy is distributed within the first order of the proposed surface grating coupler, we carefully tune the angle of the output SMF while keeping that of the input SMF at 40˚. The measured result is shown in Fig. 8. The 3dB angle bandwidth is around 7˚. This result confirms that the first order is the main order of such grating coupler. The small energy distributed angle also shows the possibility of imaging the output light onto an infrared camera in the far field.

Downloaded from SPIE Digital Library on 07 Apr 2012 to 130.237.22.49. Terms of Use: http://spiedl.org/terms

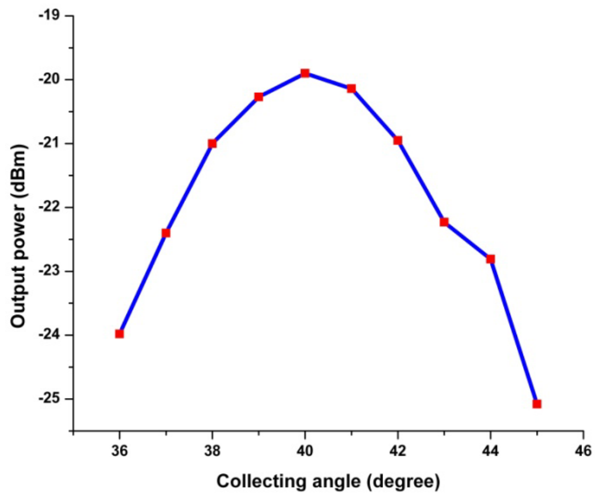


Fig. 8 The measured fiber to fiber transmission of the straight waveguide with two grating couplers at each end.

5. CONCLUSION

In this paper, a surface grating coupler based on polymer platform is proposed. A high refractive index layer of Si_3N_4 is embedded between the under cladding and waveguide layer to obtain good directionality and higher coupling efficiency with the fiber. Rather than expensive CMOS fabrication, the device is fabricated through a simple UV based soft imprint technique utilizing self-developed low loss polymer material. Around 12% of the coupling efficiency with the single mode fiber is obtained. The 3dB bandwidth centered at 1550nm is 32nm. The proposed structure would be very attractive in the applications where out of plane coupling or multiplexed signal processing is needed.

6. ACKNOWLEDGEMENTS

The authors would like to thank Steven Verstuyft and Liesbet Van Landschoot's help on the fabrication and characterization. Linghua.Wang acknowledges the support by the Chinese Scholarship Council (CSC) and by BOF co-funding from Ghent University. He also appreciates the helpful discussions with Dr. Zhechao Wang and Dr. Ananth Subramanian. This work is also supported in part by National Natural Science Foundation of China under Grant No. 60977015, No. 60807015 and No.60577014.

REFERENCES

[1] K. De Vos, J. Girones, S. Popelka, E. Schacht, R. Baets, P. Bienstman, "SOI optical microring resonator with poly(ethyleneglycol) polymer brush for label-free biosensor applications", Biosensors and Bioelectronics, 24(8), 2528-2533 (2009)

[2] D.-X. Xu, M. Vachon, A. Densmore, R. Ma, S. Janz, A. Delâge, J. Lapointe, P. Cheben, J. H. Schmid, E. Post, Sonia Messaoudène, and Jean-Marc Fédéli, "Real-time cancellation of temperature induced resonance shifts in SOI wire waveguide ring resonator label-free biosensor arrays," Opt. Express 18, 22867-22879 (2010)

[3] L. Jay Guo, "Nanoimprint lithography: methods and material requirements," Adv. Mater, 19, 495–513, (2007).

[4] J. K. S. Poon, Y. Y. Huang, G. T. Paloczi, and A. Yariv, "Soft lithography replica molding of critically coupled polymer microring resonators", IEEE Photonics Technology Letters, 16, 2496-2498, (2004).

[5] K. De Vos, Jordi Girones Molera, T. Claes, Y. De Koninck, Stepan Popelka, Etienne Schacht, R. Baets, P. Bienstman, "Multiplexed antibody detection with an array of silicon-on-insulator microring resonators", IEEE Photonics Journal, 1(4), 225-235, (2009).

[6] Hong Ma, Alex K.-Y. Jen and Larry R.Dalton, "Polymer-based optical waveguides- materials, processing,and devices," Advanced Materials, 14, 1339-1365, (2002).

[7] Louay Eldada, "Advances in polymer-based dynamic photonic components, modules, and subsystems", Proc. SPIE 6351, 63510Y-1~10, (2006).

Downloaded from SPIE Digital Library on 07 Apr 2012 to 130.237.22.49. Terms of Use: http://spiedl.org/terms

[8] C. Y. Chao and L. J. Guo, BPolymer microring resonators for biochemical sensing applications, IEEE J. Sel. Topics Quantum Electron., vol. 12, no. 1, pp. 134–142, Jan./Feb. 2006.
[9] J. B. Wright, I. Brener, K. R. Westlake, D. W. Branch, M. J. Shaw and G. A. Vawter, "A platform for multiplexed sensing of biomolecules using high-Q microring resonator arrays with differential readout and integrated microfluidics", Proc. SPIE 7605, 76050C (2010);
[10] Bruck R, Melnik E, Muellner P, Hainberger R, Lämmerhofer M, "Integrated polymer-based Mach-Zehnder interferometer label-free streptavidin biosensor compatible with injection molding", Biosensors and Bioelectronics, 26(9), 3832-3837, (2011).
[11] Jun-Whee Kim, Kyung-Jo Kim, Jeong-Ah Yi, Min-Cheol Oh, "Polymer Waveguide Label-Free Biosensors With Enhanced Sensitivity by Incorporating Low-Refractive-Index Polymers", IEEE J. Sel. Top. Quantum Electron, 16(4), 973–980, (2010).
[12] R.Waldhäusl, B. Schnabel, P. Dannberg, E.-B. Kley, A. Bräuer and W. Karthe, "Efficient coupling into polymer waveguides by gratings," Appl. Opt. 36, 9383–9390 (1997).
[13] Roman Bruck and Rainer Hainberger, "Efficient coupling of narrow beams into polyimide waveguides by means of grating couplers with high-index coating," Appl. Opt. 49, 1972-1978 (2010).
[14] Ting Han, Steve Madden, Douglas Bulla, and Barry Luther-Davies, "Low loss Chalcogenide glass waveguides by thermal nano-imprint lithography," Opt. Express 18, 19286-19291 (2010).
[15] Zhang, H.B., et al., "Synthesis of liquid polysilisiquioxane resins and properties of cured films," Thin Solid Films, vol. 517, 857-862, 2008.
[16] Zhang, H.B., et al., "A study on liquid hybrid material for waveguides - Synthesis and property of PSQ-Ls for waveguides," Journal of Macromolecular Science Part a-Pure and Applied Chemistry, vol. 45, 232-237, 2008.

Downloaded from SPIE Digital Library on 07 Apr 2012 to 130.237.22.49. Terms of Use: http://spiedl.org/terms