ACCURACY IMPROVEMENT OF RUBBER-BASED DIAPHRAGM FIBRE BRAGG GRATING PRESSURE SENSORS

VORATHIN A/L EPIN

DOCTOR OF PHILOSOPHY

UNIVERSITI MALAYSIA PAHANG

SUPERVISOR'S DECLARATION

I hereby declare that I have checked this thesis and in my opinion, this thesis is adequate in terms of scope and quality for the award of the degree of Doctor of Philosophy.

(Supervisor's Signature)

Full Name : IR. DR. MOHD HAFIZI BIN ZOHARI

Position : ASSOCIATE PROFESSOR

Date : August 9, 2021

STUDENT'S DECLARATION

I hereby declare that the work in this thesis is based on my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at Universiti Malaysia Pahang or any other institutions.

(Student's Signature)

Full Name : VORATHIN A/L EPIN

ID Number : PMV 18001

Date : August 9, 2021

ACCURACY IMPROVEMENT OF RUBBER-BASED DIAPHRAGM FIBRE BRAGG GRATING PRESSURE SENSORS

VORATHIN A/L EPIN

Thesis submitted in fulfillment of the requirements
for the award of the degree of
Doctor of Philosophy

Faculty of Mechanical & Automotive Engineering Technology
UNIVERSITI MALAYSIA PAHANG

AUGUST 2021

ACKNOWLEDGEMENTS

Dear God, thank you for giving me the good health to complete my postgraduate doctoral degree. Besides, there are several individuals and departments that I would like to thank in making this thesis a reality.

The first most important individual will be my main supervisor, Assoc. Prof. Ir. Dr. Mohd Hafizi Bin Zohari. Thank you for giving me the guidance in completing my research.

I would like to express my special thanks of gratitude to the Institute of Postgraduate Studies (IPS) and Research and Innovation Department of Universiti Malaysia Pahang for providing me the financial support under Doctoral Research Scheme (DRS) scholarship and Postgraduate Research Grants Scheme (PGRS) under grant number PGRS1903148. I would also like to thank the Advanced Structural Integrity and Vibration Research (ASIVR), Faculty of Mechanical and Automotive Engineering Technology for providing me the laboratory facilities.

My thanks and appreciation also go to Ir. Dr. Lim Kok Sing and the Photonic Research Centre, Universiti Malaya (PRCUM) for fabricating the FBG sensors. Last but not least, thank you also to the lab mates of ASIVR, Muhammad Aizzuddin Bin Abdullah, Muhammad Abdul Hadi Bin Khalili, Nur Ainaa Adhreena Binti Muhamad Shukri and Atik Faysal for their precious help during my research studies.

ABSTRAK

Penderia paras air telah menjadi satu kepentingan dalam pelbagai bidang industri. Oleh kerana kelebihannya, penderia tekanan gentian parutan Bragg (FBG) telah diperkenalkan untuk mengatasi kelemahan penderia tekanan elektrik sebagai pengukur paras air berdasarkan tekanan hidrostatik. Selama ini, pelbagai kajian telah dilaporkan mengenai penggunaan diafragma berasaskan getah untuk meningkatkan kepekaan tekanan penderia tekanan FBG mentah. Walau bagaimanapun, pengembangan terma yang tinggi daripada getah telah menjadikan penderia tekanan FBG lebih peka terhadap kesan suhu hasil daripada peningkatan kepekaan suhu. Kelemahan ini boleh mengakibatkan ketidaktepatan penderia tekanan. Oleh itu, objektif utama kajian ini adalah untuk menghilangkan kepekaan suhu agar ketepatan penderia tekanan FBG berasaskan diafragma getah dapat dipertingkatkan. Di sini, empat jenis penderia tekanan telah dihasilkan untuk mengkaji kesan suhu. Penderia tekanan jenis I adalah dengan menampal FBG mentah pada diafragma getah tanpa pampasan suhu. Penderia tekanan jenis II adalah sama dengan jenis I tetapi dengan teknik pampasan suhu rujukan FBG. Penderia tekanan jenis III dan jenis IV adalah berdasarkan teknik perbezaan FBG dan pemodulatan lebar jalur. Kesemua penderia tekanan mengalami perubahan tekanan dan suhu. Di bawah perubahan tekanan melintasi 20 kPa, kesemua penderia tekanan memperolehi kepekaan tekanan yang tinggi pada 274.8 pm/kPa, 275.0 pm/kPa, 641.9 pm/kPa dan -275.1 pm/kPa. Selain itu, penderia tekanan jenis IV juga mampu dipantau dengan menggunakan *photodetector* (PD) dengan kepekaan tekanan -12.1 mV / kPa. Di bawah perubahan suhu melintasi 50 °C, kesemua penderia tekanan memperolehi kepekaan suhu yang tinggi melebihi 44.0 pm/°C ketika dipantau berdasarkan panjang gelombang tunggal. Walau bagaimanapun, teknik perbezaan FBG dan pemodulatan lebar jalur memperolehi purata kepekaan suhu yang rendah pada 0.5 pm/°C dan -0.3 pm/°C. Oleh kerana itu, tekanan dan paras air yang diukur dengan menggunakan penderia tekanan jenis I dan jenis II jauh dari bacaan sebenar dengan ralat peratusan pada 35% dan 16.55%. Penderia tekanan jenis III dan jenis IV memperolehi purata paling tinggi ralat ketepatan pada 3.24% and 5.51%. Ini adalah kerana penderia tekanan yang tidak peka terhadap suhu tidak dipengaruhi oleh kesan suhu. Sebagai kesimpulan, dapatan kajian ini menunjukkan bahawa penggunaan diafragma getah dengan teknik perbezaan FBG dan pemodulatan lebar jalur mampu menghapuskan kepekaan suhu dan mengekalkan kepekaan tekanan yang tinggi pada penderia tekanan. Ciri-ciri kepekaan tekanan yang tinggi dan bebas suhu membolehkan penderia tekanan digunakan untuk menderia tekanan rendah dalam bidang hidrologi, pertanian, pemprosesan makanan dan sistem bekalan air dengan ketepatan yang lebih baik dan mengurangkan bacaan yang salah.

ABSTRACT

Water level sensing has become a great importance in various industrial applications. Due to its advantages, fibre Bragg grating (FBG) pressure sensor has been introduced to overcome the drawbacks of electrical pressure sensor for hydrostatic pressure based water level sensing. Over the years, various studies have been reported on the use of rubber-based diaphragms to increase the pressure sensitivity of the bare FBG pressure sensors. However, high thermal expansion of the rubber material is making the FBG pressure sensors more sensitive to the temperature effects due to the increased temperature sensitivity. This drawback can result in inaccuracy of the pressure sensors. Therefore, the main objective of this study is to eliminate the temperature sensitivity in order to improve the accuracy of the rubber-based diaphragm FBG pressure sensors. Here, four types of pressure sensors were developed to investigate the temperature effects. Type I pressure sensor was simply by bonding the bare FBG on rubber diaphragm without temperature compensation. Type II pressure sensor was similar to type I but with reference FBG temperature compensation technique. Type III and type IV pressure sensors were based on differential FBG and bandwidth modulation technique. All pressure sensors underwent pressure and temperature variations. Under pressure variation across 20 kPa, all the pressure sensors obtained high pressure sensitivity at 274.8 pm/kPa, 275.0 pm/kPa, 641.9 pm/kPa and -275.1 pm/kPa. Besides, type IV pressure sensor is also capable to be monitored using photodetector (PD) with the pressure sensitivity of -12.1 mV/kPa. Under temperature variation across 50 °C, all pressure sensors obtained high temperature sensitivity of more than 44.0 pm/°C when monitored based on single wavelength. However, the differential FBG and bandwidth modulation techniques obtained negligible average temperature sensitivity at only 0.5 pm/°C and -0.3 pm/°C. Due to this, the measured pressure and water level using type I and type II pressure sensors was far off from the actual readings with the percentage of error at 35% and 16.55%. Type III and type IV pressure sensors obtained an average highest percentage of accuracy error at only 3.24% and 5.51%. This is because the temperature effects have no influence on temperature insensitive pressure sensors. As a conclusion, the findings of this study shows that the use of rubber diaphragm with differential FBG and bandwidth modulation techniques capable to eliminate away the temperature sensitivity and retain the high pressure sensitivity of the pressure sensors. The temperature-independent high pressure sensitivity characteristics enabled the pressure sensors to be used for low pressure sensing in the fields of hydrology, agriculture, food processing and water supply system with better accuracy and reducing false information.

TABLE OF CONTENT

REFERENCES

Abang, A., & Webb, D. J. (2013). Effects of annealing, pre-tension and mounting on the hysteresis of polymer strain sensors. *Measurement Science and Technology*, 25(1), 015102–015108.

Ahmad, H., Harun, S. W., Chong, W. Y., Zulkifli, M. Z., Thant, M. M. M., Yusof, Z., & Poopalan, P. (2008). High-sensitivity pressure sensor using a polymer-embedded FBG. *Microwave and Optical Technology Letters*, 50(1), 60–61.

Allwood, G., Wild, G., Lubansky, A., & Hinckley, S. (2015). A highly sensitive fiber Bragg grating diaphragm pressure transducer. *Optical Fiber Technology*, 25, 25–32.

Ameen, O. F., Younus, M. H., Aziz, M. S., Azmi, A. I., Ibrahim, R. K. R., & Ghoshal, S. K. (2016). Graphene diaphragm integrated FBG sensors for simultaneous measurement of water level and temperature. *Sensors and Actuators A: Physical*, 252, 225–232.

Andrijasevic, D., Smetana, W., Esinenco, D., & Brenners, W. (2006). *Low temperature adhesive bonding in MEMS.* Paper presented at the 2nd International Conference on Multi-Material Micro Manufacture, Grenoble, France.

Antunes, P., Dias, J., Paixao, T., Mesquita, E., Varum, H., & Andre, P. (2015). Liquid level gauge based in plastic optical fiber. *Measurement*, 66, 238–243.

Anuszkiewicz, A., Barabach, G. S., Borsukowski, T., Olszewski, J., Martynkien, T., Urbanczyk, W., Mergo, P., Makara, M., Poturaj, K., & Geernaert, T. (2012). Sensing characteristics of the rocking filters in microstructured fibers optimized for hydrostatic pressure measurements. *Optics Express*, 20(21), 23320–23330.

Ashby, M. (2016). *Material property data for engineering materials* (4th ed.). Granta Design.

Ayyanar, N., Vigneswaran, D., Sharma, M., Sumathi, M., Rajan, M. S. M., & Konar, S. (2017). Hydrostatic pressure sensor using high birefringence photonic crystal fibers. *IEEE Sensors Journal*, 17(3), 650–656.

Bandyopadhyay, S., Shao, L., Chao, W., Yan, Z., Hong, F., Wang, G., Jiang, J., Shum, P., Hong, X., & Wang, W. (2020). Highly efficient free-space fiber coupler with 45° tilted fiber grating to access remotely placed optical fiber sensors. *Optics Express*, 28(11), 16569–16578.

Bao, L., Dong, X., Shum, P. P., & Shen, C. (2021). High sensitivity liquid level sensor based on a hollow core fiber structure. *Optics Communications*, 499, 127279–127283.

Bao, Y., Huang, Y., Hoehler, M. S., & Chen, G. (2019). Review of fiber optic sensors for structural fire engineering. *Sensors*, 19(4), 877–900.

Barabach, G. S., Kowal, D., Szczurowski, M. K., Mergo, P., & Urbanczyk, W. (2013). Hydrostatic pressure and strain sensitivity of long period grating fabricated in polymer microstructured fiber. *IEEE Photonics Technology Letters*, 25(5), 496–499.

Barile, G., Ferri, G., Parente, F. R., Stornelli, V., Sisinni, E., Depari, A., & Flammini, A. (2018). A CMOS full-range linear integrated interface for differential capacitive sensor readout. *Sensors and Actuators A: Physical*, 281, 130–140.

Barjenbruch, U., Mai, S., Ohle, N., Mertinatis, P., & Irschik, K. (2002). *Monitoring of water level, waves and ice with radar gauges.* Paper presented at the Hydro 2002 Conference, Kiel, Germany.

Baronti, F., Fantechi, G., Roncella, R., & Saletti, R. (2012). Wireless sensor node for surface seawater density measurements. *Sensors*, 12(3), 2954–2968.

Beer, F. P., Johnston, E. R. J., DeWolf, J. T., & Mazurek, D. F. (2015). *Mechanics of materials* (7th ed.). McGraw-Hill.

Bera, S. C., Mandal, H., Saha, S., & Dutta, A. (2014). Study of a modified capacitance-type level transducer for any type of liquid. *IEEE Transactions on Instrumentation and Measurement*, 63(3), 641–649.

Bhowmik, K., Peng, G. D., Luo, Y., Ambikairajah, E., Lovric, V., Walsh, W. R., & Rajan, G. (2015). Experimental study and analysis of hydrostatic pressure sensitivity of polymer fibre Bragg gratings. *Journal of Lightwave Technology*, 33(12), 2456–2462.

Bhowmik, K., Peng, G. D., Luo, Y., Ambikairajah, E., Lovric, V., Walsh, W. R., & Rajan, G. (2016). Etching process related changes and effects on solid-core single-mode polymer optical fiber grating. *IEEE Photonics Journal*, 8(1), 1–9.

Bibbo, D., Gabriele, S., Scorza, A., Schmid, M., Sciuto, S. A., & Conforto, S. (2019). A novel technique to design and optimize performances of custom load cells for sport gesture analysis. *IRBM*, 40(4), 201–210.

Birks, T. A., Knight, J. C., & Russell, P. S. J. (1997). Endlessly single-mode photonic crystal fiber. *Optics Letters*, 22(13), 961–963.

Bock, W. J., Chen, J., Mikulic, P., & Eftimov, T. (2007a). A novel fiber-optic tapered long-period grating sensor for pressure monitoring. *IEEE Transactions on Instrumentation and Measurement*, 56(4), 1176–1180.

Bock, W. J., Chen, J., Mikulic, P., Eftimov, T., & Pawlowski, M. K. (2007b). Pressure sensing using periodically tapered long-period gratings written in photonic crystal fibres. *Measurement Science and Technology*, 18(10), 3098–3102.

Boyes, W. (2009). *Instrumentation reference book* (4th ed.). Butterworth-Heinemann.

Bragg, W. H. (1913). The reflection of X-rays by crystals. *Nature*, 91(2280), 477–477.

Brumbi, D. (1995). *Measuring process and storage tank level with radar technology.* Paper presented at the 1995 IEEE International Radar Conference, Virginia, United States.

Bundalo, I. L., Lwin, R., Saval, S. L., & Argyros, A. (2016). All-plastic fiber-based pressure sensor. *Applied Optics*, 55(4), 811–816.

Cai, J. X., Feng, K. M., Willner, A. E., Grubsky, V., Starodubov, D. S., & Feinberg, J. (1999). Simultaneous tunable dispersion compensation of many WDM channels using a sampled nonlinearly chirped fiber Bragg grating. *IEEE Photonics Technology Letters*, 11(11), 1455–1457.

Campanella, C., Cuccovillo, A., Campanella, C., Yurt, A., & Passaro, V. (2018). Fibre Bragg grating based strain sensors: Review of technology and applications. *Sensors*, 18(9), 3115–3142.

Canbolat, H. (2009). A novel level measurement technique using three capacitive sensors for liquids. *IEEE Transactions on Instrumentation and Measurement*, 58(10), 3762–3768.

Carvalho, J. P., Anuszkiewicz, A., Barabach, G. S., Baptista, J. M., Frazao, O., Mergo, P., Santos, J. L., & Urbanczyk, W. (2012). Long period gratings and rocking filters written with a CO_2 laser in highly-birefringent boron-doped photonic crystal fibers for sensing applications. *Optics Communications*, 285(3), 264–268.

Chang, H. Y., Chang, Y. C., & Liu, W. F. (2017). A highly sensitive two-dimensional inclinometer based on two etched chirped-fiber-grating arrays. *Sensors*, 17(12), 2922–2931.

Chen, D., Hu, G., & Chen, L. (2011). Dual-core photonic crystal fiber for hydrostatic pressure sensing. *IEEE Photonics Technology Letters*, 23(24), 1851–1854.

Chen, G., Liu, L., Jia, H., Yu, J., Xu, L., & Wang, W. (2003). Simultaneous pressure and temperature measurement using Hi-Bi fiber Bragg gratings. *Optics Communications*, 228(1–3), 99–105.

Chen, S., Liu, Y., Liu, X., Zhang, Y., & Peng, W. (2015). Self-compensating displacement sensor based on hydramatic structured transducer and fiber Bragg grating. *Photonic Sensors*, 5(4), 351–356.

Chen, W. P., Wang, D. N., Xu, B., Zhao, C. L., & Chen, H. F. (2017). Multimode fiber tip Fabry-Perot cavity for highly sensitive pressure measurement. *Scientific Reports*, 7(1), 368–374.

Chiavaioli, F., Gouveia, C., Jorge, P., & Baldini, F. (2017). Towards a uniform metrological assessment of grating-based optical fiber sensors: From refractometers to biosensors. *Biosensors*, 7(2), 23–52.

Chmielewska, E., Urbanczyk, W., & Bock, W. J. (2003). Measurement of pressure and temperature sensitivities of a Bragg grating imprinted in a highly birefringent side-hole fiber. *Applied Optics*, 42(31), 6284–6291.

Dean, J. A., & Lange, N. A. (1999). *Lange's handbook of chemistry* (15th ed.). McGraw-Hill.

Diaz, C. A. R., Leal, J. A. G., Andre, P. S. B., Antunes, P. F. D. C., Pontes, M. J., Neto, A. F., & Ribeiro, M. R. N. (2018). Liquid level measurement based on FBG-embedded diaphragms with temperature compensation. *IEEE Sensors Journal*, 18(1), 193–200.

Dimmick, T. E., Kakarantzas, G., Birks, T. A., & Russell, P. S. J. (1999). Carbon dioxide laser fabrication of fused-fiber couplers and tapers. *Applied Optics*, 38(33), 6845–6848.

Dong, C., Li, K., Jiang, Y., Arola, D., & Zhang, D. (2018). Evaluation of thermal expansion coefficient of carbon fiber reinforced composites using electronic speckle interferometry. *Optics Express*, 26(1), 531–543.

Dong, X., Liu, Y., Liu, Z., & Dong, X. (2001). Simultaneous displacement and temperature measurement with cantilever-based fiber Bragg grating sensor. *Optics Communications*, 192(3), 213–217.

Dong, X. W., Liu, W. K., & Zhao, R. F. (2013). Liquid-level sensor based on tapered chirped fiber grating. *Science China Technological Sciences*, 56(2), 471–474.

Faria, J., Sousa, A., Reis, A., Filipe, V., & Barroso, J. (2016). Probe and sensors development for level measurement of fats, oils and grease in grease boxes. *Sensors*, 16(9), 1517–1537.

Francis, T. S. Y., & Yin, S. (2002). *Fiber optic sensors*. Marcel Dekker Inc.

Fu, H. Y., Tam, H. Y., Shao, L. Y., Dong, X., Wai, P. K. A., Lu, C., & Khijwania, S. K. (2008). Pressure sensor realized with polarization-maintaining photonic crystal fiber-based Sagnac interferometer. *Applied Optics*, 47(15), 2835–2839.

Fu, H. Y., Wu, C., Tse, M. L. V., Zhang, L., Cheng, K. C. D., Tam, H. Y., Guan, B. O., & Lu, C. (2010). High pressure sensor based on photonic crystal fiber for downhole application. *Applied Optics*, 49(14), 2639–2643.

Gu, Y. F., Zhao, Y., Lv, R. Q., & Yang, Y. (2016). A practical FBG sensor based on a thin-walled cylinder for hydraulic pressure measurement. *IEEE Photonics Technology Letters*, 28(22), 2569–2572.

Guan, B. O., Chen, D., Zhang, Y., Wang, H. J., & Tam, H. Y. (2008). Bragg gratings in pure-silica polarization-maintaining photonic crystal fiber. *IEEE Photonics Technology Letters*, 20(23), 1980–1982.

Guo, T., Vila, A. G., Loyez, M., & Caucheteur, C. (2017). Plasmonic optical fiber-grating immunosensing: A review. *Sensors*, 17(12), 2732–2752.

Guo, T., Zhao, Q., Dou, Q., Zhang, H., Xue, L., Huang, G., & Dong, X. (2005). Temperature-insensitive fiber Bragg grating liquid-level sensor based on bending cantilever beam. *IEEE Photonics Technology Letters*, 17(11), 2400–2402.

He, H., Wang, L., & Yin, L. (2014). Asymmetric elliptical-hole dual-core photonic crystal fiber with enhanced pressure sensitivity. *Optical Fiber Technology*, 20(4), 380–383.

Hill, K. O., Bilodeau, F., Malo, B., Kitagawa, T., Theriault, S., Johnson, D. C., Albert, J., & Takiguchi, K. (1994). Chirped in-fiber Bragg gratings for compensation of optical-fiber dispersion. *Optics Letters*, 19(17), 1314–1316.

Hill, K. O., Fujii, Y., Johnson, D. C., & Kawasaki, B. S. (1978). Photosensitivity in optical fiber waveguides: Application to reflection filter fabrication. *Applied Physics Letters*, 32(10), 647–649.

Hill, K. O., Malo, B., Bilodeau, F., Johnson, D. C., & Albert, J. (1993). Bragg gratings fabricated in monomode photosensitive optical fiber by UV exposure through a phase mask. *Applied Physics Letters*, 62(10), 1035–1037.

Hill, K. O., Malo, B., Vineberg, K. A., Bilodeau, F., Johnson, D. C., & Skinner, I. (1990). Efficient mode conversion in telecommunication fibre using externally written gratings. *Electronics Letters*, 26(16), 1270–1272.

Hsu, Y. S., Wang, L., Liu, W. F., & Chiang, Y. J. (2006). Temperature compensation of optical fiber Bragg grating pressure sensor. *IEEE Photonics Technology Letters*, 18(7), 874–876.

Hu, G., & Chen, D. (2012). Side-hole dual-core photonic crystal fiber for hydrostatic pressure sensing. *Journal of Lightwave Technology*, 30(14), 2382–2387.

Hu, X., Kinet, D., Megret, P., & Caucheteur, C. (2016). Control over photo-inscription and thermal annealing to obtain high-quality Bragg gratings in doped PMMA optical fibers. *Optics Letters*, 41(13), 2930–2933.

Huang, J., Zhou, Z., Wen, X., & Zhang, D. (2013a). A diaphragm-type fiber Bragg grating pressure sensor with temperature compensation. *Measurement*, 46(3), 1041–1046.

Huang, J., Zhou, Z., Zhang, D., & Wei, Q. (2013b). A fiber Bragg grating pressure sensor and its application to pipeline leakage detection. *Advances in Mechanical Engineering*, 5, 590451–590457.

Huang, J. Y., Roosbroeck, J. V., Vlekken, J., Martinez, A. B., Geernaert, T., Berghmans, F., Hoe, B. V., Lindner, E., & Caucheteur, C. (2017). FBGs written in specialty fiber for high pressure/high temperature measurement. *Optics Express*, 25(15), 17936–17947.

Huang, W. P. (1994). Coupled-mode theory for optical waveguides: An overview. *Journal of the Optical Society of America A*, 11(3), 963–983.

Hui, R. (2019). *Introduction to fiber-optic communications*. Academic Press.

Hunt, J. A. (2007). Level sensing of liquids and solids–A review of the technologies. *Sensor Review*, 27(3), 200–206.

Iadicicco, A., & Campopiano, S. (2015). Sensing features of long period gratings in hollow core fibers. *Sensors*, 15(4), 8009–8019.

Ishikawa, R., Lee, H., Lacraz, A., Theodosiou, A., Kalli, K., Mizuno, Y., & Nakamura, K. (2017). Pressure dependence of fiber Bragg grating inscribed in perfluorinated polymer fiber. *IEEE Photonics Technology Letters*, 29(24), 2167–2170.

Ismail, N. N., Sharbirin, A. S., Saad, M. S. M., Zaini, M. K. A., Ismail, M. F., Brambilla, G., Rahman, B. M. A., Grattan, K. T. V., & Ahmad, H. (2021). Novel 3D-printed biaxial tilt sensor based on fiber Bragg grating-based sensing approach. *Sensors and Actuators A: Physical*, 112864–112872.

Jang, M., Kim, J. S., Um, S. H., Yang, S., & Kim, J. (2019). Ultra-high curvature sensors for multi-bend structures using fiber Bragg gratings. *Optics Express*, 27(3), 2074–2084.

Jaworski, A. J., & Meng, G. (2009). On-line measurement of separation dynamics in primary gas/oil/water separators: challenges and technical solutions–A review. *Journal of Petroleum Science and Engineering*, 68(1–2), 47–59.

Jewart, C. M., Quintero, S. M., Braga, A. M. B., & Chen, K. P. (2010). Design of a highly-birefringent microstructured photonic crystal fiber for pressure monitoring. *Optics Express*, 18(25), 25657–25664.

Jiang, B., Yin, G., Zhou, K., Wang, C., Gan, X., Zhao, J., & Zhang, L. (2016). Graphene-induced unique polarization tuning properties of excessively tilted fiber grating. *Optics Letters*, 41(23), 5450–5453.

Jiang, M., Zhang, A. P., Wang, Y. C., Tam, H. Y., & He, S. (2009). Fabrication of a compact reflective long-period grating sensor with a cladding-mode-selective fiber end-face mirror. *Optics Express*, 17(20), 17976–17982.

Jiang, N., Zhu, H., Bao, K., & Hu, Y. (2015). Simultaneous discrimination of strain and temperature using dual-gratings in one fiber. *Optik*, 126(23), 3974–3977.

Jin, B., Zhang, W., Ren, F., Zhang, M., Dai, W., & Wang, Y. (2017). Mechanism of subordinate peak skewing of FBG sensor during cracks propagation monitoring on aluminum alloy structure. *Journal of Sensors*, 2017, 1–7.

Kakarantzas, G., Blanch, A. O., Birks, T. A., Russell, P. S. J., Farr, L., Couny, F., & Mangan, B. J. (2003). Structural rocking filters in highly birefringent photonic crystal fiber. *Optics Letters*, 28(3), 158–160.

Kashyap, R., Wyatt, R., & Campbell, R. J. (1993). Wideband gain flattened erbium fibre amplifier using a photosensitive fibre blazed grating. *Electronics Letters*, 29(2), 154–156.

Khalid, K., Grozescu, I. V., Tiong, L. K., Sim, L. T., & Mohd, R. (2003). Water detection in fuel tanks using the microwave reflection technique. *Measurement Science and Technology*, 14(11), 1905–1911.

Kim, B., Jin, Y., Lee, J., & Kim, S. (2020). Low-complexity MUSIC-based direction-of-arrival detection algorithm for frequency-modulated continuous-wave vital radar. *Sensors*, 20(15), 4295–4313.

Kim, Y. Y., & Kwon, Y. E. (2015). Review of magnetostrictive patch transducers and applications in ultrasonic nondestructive testing of waveguides. *Ultrasonics*, 62, 3–19.

Knight, J. C., Birks, T. A., Russell, P. S. J., & Atkin, D. M. (1996). All-silica single-mode optical fiber with photonic crystal cladding. *Optics Letters*, 21(19), 1547–1549.

Knight, J. C., Broeng, J., Birks, T. A., & Russell, P. S. J. (1998). Photonic band gap guidance in optical fibers. *Science*, 282(5393), 1476–1478.

Korganbayev, S., Orazayev, Y., Sovetov, S., Bazyl, A., Schena, E., Massaroni, C., Gassino, R., Vallan, A., Perrone, G., & Saccomandi, P. (2018). Detection of thermal gradients through fiber-optic chirped fiber Bragg grating (CFBG): Medical thermal ablation scenario. *Optical Fiber Technology*, 41, 48–55.

Kuang, Y., Guo, Y., Xiong, L., & Liu, W. (2018). Packaging and temperature compensation of fiber Bragg grating for strain sensing: A survey. *Photonic Sensors*, 8(4), 320–331.

Kulkarni, A., Karekar, R. N., & Aiyer, R. C. (2005). Liquid level sensor. *Review of Scientific Instruments*, 76(10), 105108–105113.

Lamberti, A., Chiesura, G., Luyckx, G., Degrieck, J., Kaufmann, M., & Vanlanduit, S. (2015). Dynamic strain measurements on automotive and aeronautic composite components by means of embedded fiber Bragg grating sensors. *Sensors*, 15(10), 27174–27200.

Large, M. C. J., Blacket, D., & Bunge, C. A. (2010). Microstructured polymer optical fibers compared to conventional POF: Novel properties and applications. *IEEE Sensors Journal*, 10(7), 1213–1217.

Laxmeshwar, L. S., Jadhav, M. S., Akki, J. F., Raikar, P., Kumar, J., Mahakud, R., & Raikar, U. S. (2018). Quantification of chloride and iron in sugar factory effluent using long period fiber grating chemical sensor. *Sensors and Actuators B: Chemical*, 258, 850–856.

Lazaro, R. C., Marques, C. A. F., Castellani, C. E. S., & Leal, J. A. G. (2021). FBG-based measurement systems for density, specific heat capacity and thermal conductivity assessment for liquids. *IEEE Sensors Journal*, 21(6), 7657–7664.

Leal, J. A. G., Neto, A. F., Diaz, C. A. R., Marques, C. A. F., Ribeiro, M. R. N., & Pontes, M. J. (2018). Material features based compensation technique for the temperature effects in a polymer diaphragm-based FBG pressure sensor. *Optics Express*, 26(16), 20590–20602.

Lee, B. H., Eom, J. B., Park, K. S., Park, S. J., & Ju, M. J. (2010). Specialty fiber coupler: Fabrications and applications. *Journal of the Optical Society of Korea*, 14(4), 326–332.

Lee, B. H., Kim, Y. H., Park, K. S., Eom, J. B., Kim, M. J., Rho, B. S., & Choi, H. Y. (2012). Interferometric fiber optic sensors. *Sensors*, 12(3), 2467–2486.

Lee, B. Y., Kim, J., Kim, H., Kim, C., & Lee, S. D. (2016). Low-cost flexible pressure sensor based on dielectric elastomer film with micro-pores. *Sensors and Actuators A: Physical*, 240, 103–109.

Lemaire, P. J., Vengsarkar, A. M., Reed, W. A., Mizrahi, V., & Kranz, K. S. (1994). *Refractive-index changes in optical fibers sensitized with molecular hydrogen.* Paper presented at the 1994 Optical Fiber Communication Conference, California, United States.

Li, P., Cai, Y., Shen, X., Nabuzaale, S., Yin, J., & Li, J. (2014). An accurate detection for dynamic liquid level based on MIMO ultrasonic transducer array. *IEEE Transactions on Instrumentation and Measurement*, 64(3), 582–595.

Li, X. P., Li, Y., Li, X. F., Song, D., Min, P., Hu, C., Zhang, H. B., Koratkar, N., & Yu, Z. Z. (2019). Highly sensitive, reliable and flexible piezoresistive pressure sensors featuring polyurethane sponge coated with MXene sheets. *Journal of Colloid and Interface Science*, 542, 54–62.

Li, Z., Liao, C., Wang, Y., Xu, L., Wang, D., Dong, X., Liu, S., Wang, Q., Yang, K., & Zhou, J. (2015). Highly-sensitive gas pressure sensor using twin-core fiber based in-line Mach-Zehnder interferometer. *Optics Express*, 23(5), 6673–6678.

Liang, H., Jia, P., Liu, J., Fang, G., Li, Z., Hong, Y., Liang, T., & Xiong, J. (2018a). Diaphragm-free fiber-optic Fabry-Perot interferometric gas pressure sensor for high temperature application. *Sensors*, 18(4), 1011–1022.

Liang, M. F., Fang, X. Q., & Ning, Y. S. (2018b). Temperature compensation fiber Bragg grating pressure sensor based on plane diaphragm. *Photonic Sensors*, 8(2), 157–167.

Liang, M. F., Fang, X. Q., Wu, G., Xue, G. Z., & Li, H. W. (2017). A fiber Bragg grating pressure sensor with temperature compensation based on diaphragm-cantilever structure. *Optik*, 145, 503–512.

Liao, C., Liu, S., Xu, L., Wang, C., Wang, Y., Li, Z., Wang, Q., & Wang, D. N. (2014). Sub-micron silica diaphragm-based fiber-tip Fabry-Perot interferometer for pressure measurement. *Optics Letters*, 39(10), 2827–2830.

Lim, K. S., Yang, H. Z., Chong, W. Y., Cheong, Y. K., Lim, C. H., Ali, N. M., & Ahmad, H. (2013). Axial contraction in etched optical fiber due to internal stress reduction. *Optics Express*, 21(3), 2551–2562.

Lin, C. M., Liu, Y. C., Liu, W. F., Fu, M. Y., Sheng, H. J., Bor, S. S., & Tien, C. L. (2006). High-sensitivity simultaneous pressure and temperature sensor using a superstructure fiber grating. *IEEE Sensors Journal*, 6(3), 691–696.

Liu, F., Guo, T., Wu, C., Guan, B. O., Lu, C., Tam, H. Y., & Albert, J. (2014). Wideband-adjustable reflection-suppressed rejection filters using chirped and tilted fiber gratings. *Optics Express*, 22(20), 24430–24438.

Liu, L., Li, Y., He, Y., Li, F., & Liu, Y. (2009). Membrane-based fiber Bragg grating pressure sensor with high sensitivity. *Microwave and Optical Technology Letters*, 51(5), 1279–1281.

Liu, Y., Guo, Z., Zhang, Y., Chiang, K. S., & Dong, X. (2000). Simultaneous pressure and temperature measurement with polymer-coated fibre Bragg grating. *Electronics Letters*, 36(6), 564–566.

Liu, Y., Li, L., Zhao, L., Wang, J., & Liu, T. (2017). Research on a new fiber-optic axial pressure sensor of transformer winding based on fiber Bragg grating. *Photonic Sensors*, 7(4), 365–371.

Liu, Y., Liu, B., Feng, X., Zhang, W., Zhou, G., Yuan, S., Kai, G., & Dong, X. (2005). High-birefringence fiber loop mirrors and their applications as sensors. *Applied Optics*, 44(12), 2382–2390.

Ma, J., Ju, J., Jin, L., & Jin, W. (2011). A compact fiber-tip micro-cavity sensor for high-pressure measurement. *IEEE Photonics Technology Letters*, 23(21), 1561–1563.

Machavaram, V. R., Badcock, R. A., & Fernando, G. F. (2007). Fabrication of intrinsic fibre Fabry-Perot sensors in silica fibres using hydrofluoric acid etching. *Sensors and Actuators A: Physical*, 138(1), 248–260.

Mackowiak, V., Peupelmann, J., Ma, Y., & Gorges, A. (2015). *NEP-noise equivalent power*. Thorlabs, Inc.

Mamedov, V. T., Mamedov, G. A., & Aslanov, J. N. (2020). Stress-strain state of sealing rubber membranes at large deformations. *Journal of Applied Mechanics and Technical Physics*, 61(2), 286–291.

Manuvinakurake, M., Gandhi, U., Mangalanathan, U., & Nayak, M. (2018). Design, fabrication and testing of fiber bragg grating based fixed guided beam pressure sensor. *Optik*, 158, 1063–1072.

Marchenko, A., Lishman, B., Wrangborg, D., & Thiel, T. (2016). Thermal expansion measurements in fresh and saline ice using fiber optic strain gauges and multipoint temperature sensors based on Bragg gratings. *Journal of Sensors*, 2016, 1–13.

Marques, C. A. F., Peng, G. D., & Webb, D. J. (2015). Highly sensitive liquid level monitoring system utilizing polymer fiber Bragg gratings. *Optics Express*, 23(5), 6058–6072.

Marques, C. A. F., Pospori, A., Rodriguez, D. S., Nielsen, K., Bang, O., & Webb, D. J. (2016). Aviation Fuel Gauging Sensor Utilizing Multiple Diaphragm Sensors Incorporating Polymer Optical Fiber Bragg Gratings. *IEEE Sensors Journal*, 16(15), 6122–6129.

Meltz, G., Morey, W. W., & Glenn, W. H. (1989). Formation of Bragg gratings in optical fibers by a transverse holographic method. *Optics Letters*, 14(15), 823–825.

Mihailov, S. J. (2012). Fiber Bragg grating sensors for harsh environments. *Sensors*, 12(2), 1898–1918.

Mora, J., Villatoro, J., Diez, A., Cruz, J. L., & Andres, M. V. (2002). Tunable chirp in Bragg gratings written in tapered core fibers. *Optics Communications*, 210(1), 51–55.

Musayev, E., & Karlik, S. E. (2003). A novel liquid level detection method and its implementation. *Sensors and Actuators A: Physical*, 109(1), 21–24.

Nakagawa, T., Hyodo, A., Kogo, K., Kurata, H., Osada, K., & Oho, S. (2012). Contactless liquid-level measurement with frequency-modulated millimeter wave through opaque container. *IEEE Sensors Journal*, 13(3), 926–933.

Nascimento, K. P., Neto, A. F., Marques, C. A. F., & Leal, J. A. G. (2021). Machine learning techniques for liquid level estimation using FBG temperature sensor array. *Optical Fiber Technology*, 65, 102612–102621.

Neeharika, V., & Pattnaik, P. K. (2016). Optical MEMS pressure sensors incorporating dual waveguide Bragg gratings on diaphragms. *IEEE Sensors Journal*, 16(3), 681–687.

Nikolov, G., & Nikolova, B. (2008). Virtual techniques for liquid level monitoring using differential pressure sensors. *Recent*, 9(2), 49–55.

Oliveira, R., Bilro, L., & Nogueira, R. (2018). Strain sensitivity control of an in-series silica and polymer FBG. *Sensors*, 18(6), 1884–1893.

Osorio, J. H., Hayashi, J. G., Espinel, Y. A. V., Franco, M. A. R., Andres, M. V., & Cordeiro, C. M. B. (2014). Photonic-crystal fiber-based pressure sensor for dual environment monitoring. *Applied Optics*, 53(17), 3668–3672.

Pachava, V. R., Kamineni, S., Madhuvarasu, S. S., & Putha, K. (2013). *Diaphragm based high sensitive FBG pressure sensor*. Paper presented at the 2013 International Conference on Optics in Precision Engineering and Nanotechnology, Singapore.

Pachava, V. R., Kamineni, S., Madhuvarasu, S. S., & Putha, K. (2014a). A high sensitive FBG pressure sensor using thin metal diaphragm. *Journal of Optics*, 43(2), 117–121.

Pachava, V. R., Kamineni, S., Madhuvarasu, S. S., & Putha, K. (2014b). Polymer packaged fiber grating pressure sensor with enhanced sensitivity. *International Journal of Optoelectronic Engineering*, 4(1), 1–5.

Pachava, V. R., Kamineni, S., Madhuvarasu, S. S., Putha, K., & Mamidi, V. R. (2015). FBG based high sensitive pressure sensor and its low-cost interrogation system with enhanced resolution. *Photonic Sensors*, 5(4), 321–329.

Palumbo, G., Tosi, D., Iadicicco, A., & Campopiano, S. (2018). Analysis and design of chirped fiber Bragg grating for temperature sensing for possible biomedical applications. *IEEE Photonics Journal*, 10(3), 1–15.

Peng, B. J., Zhao, Y., Yang, J., & Zhao, M. (2005). Pressure sensor based on a free elastic cylinder and birefringence effect on an FBG with temperature-compensation. *Measurement*, 38(2), 176–180.

Peng, G. D., Xiong, Z., & Chu, P. L. (1999). Photosensitivity and gratings in dye-doped polymer optical fibers. *Optical Fiber Technology*, 5(2), 242–251.

Pernia, A. M., Mayor, H. A., Prieto, M. J., Villegas, P. J., Nuno, F., & Ramos, J. A. M. (2019). Magnetostrictive sensor for blockage detection in pipes subjected to high temperatures. *Sensors*, 19(10), 2382–2399.

Pinto, A. M. R., & Amo, M. L. (2012). Photonic crystal fibers for sensing applications. *Journal of Sensors*, 2012, 1–21.

Pisco, M., Iadicicco, A., Campopiano, S., Cutolo, A., & Cusano, A. (2008). Structured chirped fiber Bragg gratings. *Journal of Lightwave Technology*, 26(12), 1613–1625.

Polivka, J. (2007). An overview of microwave sensor technology. *High Frequency Electronics*, 6(4), 32–42.

Pospori, A., Marques, C. A. F., Rodriguez, D. S., Nielsen, K., Bang, O., & Webb, D. J. (2017). Thermal and chemical treatment of polymer optical fiber Bragg grating sensors for enhanced mechanical sensitivity. *Optical Fiber Technology*, 36, 68–74.

Pospori, A., Marques, C. A. F., Sagias, G., Rivera, H. L., & Webb, D. J. (2018). Novel thermal annealing methodology for permanent tuning polymer optical fiber Bragg gratings to longer wavelengths. *Optics Express*, 26(2), 1411–1421.

Quero, G., Zuppolini, S., Consales, M., Diodato, L., Vaiano, P., Venturelli, A., Santucci, M., Spyrakis, F., Costi, M. P., & Giordano, M. (2016). Long period fiber grating working in reflection mode as valuable biosensing platform for the detection of drug resistant bacteria. *Sensors and Actuators B: Chemical*, 230, 510–520.

Rahman, N., Deaton, N. J., Sheng, J., Cheng, S. S., & Desai, J. P. (2019). Modular FBG bending sensor for continuum neurosurgical robot. *IEEE Robotics and Automation Letters*, 4(2), 1424–1430.

Rajan, G., Bhowmik, K., Xi, J., & Peng, G. D. (2017). Etched polymer fibre Bragg gratings and their biomedical sensing applications. *Sensors*, 17(10), 2336–2349.

Rajan, G., Liu, B., Luo, Y., Ambikairajah, E., & Peng, G. D. (2013). High sensitivity force and pressure measurements using etched singlemode polymer fiber Bragg gratings. *IEEE Sensors Journal*, 13(5), 1794–1800.

Ran, Z., Liu, S., Liu, Q., Wang, Y., Bao, H., & Rao, Y. (2015). Novel high-temperature fiber-optic pressure sensor based on etched PCF F-P interferometer micromachined by a 157-nm laser. *IEEE Sensors Journal*, 15(7), 3955–3958.

Ran, Z. L., Rao, Y. J., Liu, W. J., Liao, X., & Chiang, K. S. (2008). Laser-micromachined Fabry-Perot optical fiber tip sensor for high-resolution temperature-independent measurement of refractive index. *Optics Express*, 16(3), 2252–2263.

Rito, R. L., Crocombe, A. D., & Ogin, S. L. (2017). Health monitoring of composite patch repairs using CFBG sensors: Experimental study and numerical modelling. *Composites Part A: Applied Science and Manufacturing*, 100, 255–268.

Sakharov, V. E., Kuznetsov, S. A., Zaitsev, B. D., Kuznetsova, I. E., & Joshi, S. G. (2003). Liquid level sensor using ultrasonic Lamb waves. *Ultrasonics*, 41(4), 319–322.

Schenato, L., Lopez, J. P. A., Galtarossa, A., Pasuto, A., Bogaard, T., & Palmieri, L. (2021). A rugged FBG-based pressure sensor for water level monitoring in dikes. *IEEE Sensors Journal*, 21(12), 13263–213271.

Schenato, L., Rong, Q., Shao, Z., Qiao, X., Pasuto, A., Galtarossa, A., & Palmieri, L. (2019). Highly-sensitive FBG pressure sensor based on a 3D-printed transducer. *Journal of Lightwave Technology*, 37(18), 4784–4790.

Schmid, S. R., Hamrock, B. J., & Jacobson, B. O. (2014). *Fundamentals of machine elements: SI version* (3rd ed.). CRC Press.

Sheng, H. J., Fu, M. Y., Chen, T. C., Liu, W. F., & Bor, S. S. (2004). A lateral pressure sensor using a fiber Bragg grating. *IEEE Photonics Technology Letters*, 16(4), 1146–1148.

Sikora, A. (2016). Parameter comparison of fiber Bragg grating based optical wavelength discriminators. *Measurement Automation Monitoring*, 62(8), 265–267.

Silva, S., Coelho, L., Malcata, F. X., Becker, M., Rothhardt, M. W., Bartelt, H., & Frazao, O. (2012). *Hydrogen pressure sensor based on a tapered-FBG written by DUV femtosecond laser technique.* Paper presented at the Access Networks and In-house Communications 2012, Colorado, United States.

Silva, S., Ferreira, L. A., Araujo, F. M., Santos, J. L., & Frazao, O. (2011). Fiber Bragg grating structures with fused tapers. *Fiber and Integrated Optics*, 30(1), 9–28.

Sindhanaiselvi, D. (2015). *Design and analysis of low pressure MEMS sensor.* (Doctoral dissertation, Pondicherry University). Retrieved from http://shodhganga.inflibnet.ac.in/handle/10603/160536

Smietana, M., Bock, W. J., Mikulic, P., & Chen, J. (2010). Increasing sensitivity of arc-induced long-period gratings: Pushing the fabrication technique toward its limits. *Measurement Science and Technology*, 22(1), 015201–015207.

Smietana, M., Bock, W. J., Mikulic, P., & Chen, J. (2012). Tuned pressure sensitivity of dual resonant long-period gratings written in boron co-doped optical fiber. *Journal of Lightwave Technology*, 30(8), 1080–1084.

Song, D., Wei, Z., Zou, J., Yang, S., Du, E., & Cui, H. L. (2009). Pressure sensor based on fiber Bragg grating and carbon fiber ribbon-wound composite cylindrical shell. *IEEE Sensors Journal*, 9(7), 828–831.

Stano, G., Nisio, A. D., Lanzolla, A., & Percoco, G. (2020). Additive manufacturing and characterization of a load cell with embedded strain gauges. *Precision Engineering*, 62, 113–120.

Sulejmani, S., Sonnenfeld, C., Geernaert, T., Mergo, P., Makara, M., Poturaj, K., Skorupski, K., Martynkien, T., & Olszewski, J. (2012). Control over the pressure sensitivity of Bragg grating-based sensors in highly birefringent microstructured optical fibers. *IEEE Photonics Technology Letters*, 24(6), 527–529.

Sun, A., Qiao, X. G., Jia, Z. A., Li, M., & Zhao, D. Z. (2005). Study of simultaneous measurement of temperature and pressure using double fiber Bragg gratings with polymer package. *Optical Engineering*, 44(3), 034402–034406.

Sun, B., Wang, Y., Qu, J., Liao, C., Yin, G., He, J., Zhou, J., Tang, J., Liu, S., & Li, Z. (2015). Simultaneous measurement of pressure and temperature by employing Fabry-Perot interferometer based on pendant polymer droplet. *Optics Express*, 23(3), 1906–1911.

Suo, R., Chen, X., Zhou, K., Zhang, L., & Bennion, I. (2009). In-fibre directional transverse loading sensor based on excessively tilted fibre Bragg gratings. *Measurement Science and Technology*, 20(3), 034015–034021.

Tahir, B. A., Ali, J., & Rahman, R. A. (2006). Fabrication of fiber grating by phase mask and its sensing application. *Journal of Optoelectronics and Advanced Materials*, 8(4), 1604–1609.

Tang, J., Yin, G., Liu, S., Zhong, X., Liao, C., Li, Z., Wang, Q., & Zhao, J. (2015). Gas pressure sensor based on CO_2-laser-induced long-period fiber grating in air-core photonic bandgap fiber. *IEEE Photonics Journal*, 7(5), 6803107–6803114.

Tang, J., Zhang, Z., Yin, G., Liu, S., Bai, Z., Li, Z., Deng, M., & Wang, Y. (2017). Long period fiber grating inscribed in hollow-core photonic bandgap fiber for gas pressure sensing. *IEEE Photonics Journal*, 9(5), 7105307–7105314.

Tasri, A., & Susilawati, A. (2019). Effect of material of post-cooling pipes on temperature and thermal stress in mass concrete. *Structures*, 20, 204–212.

Terzic, J., Nagarajah, C. R., & Alamgir, M. (2010). Fluid level measurement in dynamic environments using a single ultrasonic sensor and support vector machine (SVM). *Sensors and Actuators A: Physical*, 161(1–2), 278–287.

Timoshenko, S. P., & Krieger, S. W. (1959). *Theory of plates and shells* (2nd ed.). McGraw-Hill.

Tosi, D. (2018). Review of chirped fiber Bragg grating (CFBG) fiber-optic sensors and their applications. *Sensors*, 18(7), 2147–2179.

Tsai, W. H., & Lin, C. J. (2001). A novel structure for the intrinsic Fabry-Perot fiber-optic temperature sensor. *Journal of Lightwave Technology*, 19(5), 682–686.

Tsuda, H. (2006). Ultrasound and damage detection in CFRP using fiber Bragg grating sensors. *Composites Science and Technology*, 66(5), 676–683.

Vengsarkar, A. M., Pedrazzani, J. R., Judkins, J. B., Lemaire, P. J., Bergano, N. S., & Davidson, C. R. (1996). Long-period fiber-grating-based gain equalizers. *Optics Letters*, 21(5), 336–338.

Villatoro, J., Minkovich, V. P., & Hernandez, D. M. (2006). Compact modal interferometer built with tapered microstructured optical fiber. *IEEE Photonics Technology Letters*, 18(11), 1258–1260.

Vinogradov, S., Cobb, A., & Fisher, J. (2018). New magnetostrictive transducer designs for emerging application areas of NDE. *Materials*, 11(5), 755–768.

Vivek, K., Rajesh, R., Sreehari, C. V., Sham, K. S., Shajahan, K., Praveen, T. V., Santhanakrishnan, T., & Moosad, K. P. B. (2017). A new approach of large diameter polymer-coated fiber laser hydrophone. *Journal of Lightwave Technology*, 35(19), 4097–4104.

Wang, D. H. C., Blenman, N., Maunder, S., Patton, V., & Arkwright, J. (2013). An optical fiber Bragg grating force sensor for monitoring sub-bandage pressure during compression therapy. *Optics Express*, 21(17), 19799–19807.

Wang, R., Si, J., Chen, T., Yan, L., Cao, H., Pham, X., & Hou, X. (2017). Fabrication of high-temperature tilted fiber Bragg gratings using a femtosecond laser. *Optics Express*, 25(20), 23684–23689.

Wang, S. W., Chen, C. C., Wu, C. M., & Huang, C. M. (2018). *A continuous water-level sensor based on load cell and floating pipe.* Paper presented at the 2018 IEEE International Conference on Applied System Invention, Chiba, Japan.

Wang, Y. L., Yang, C. H., Jan, H. Y. C., Lin, G. R., Mau, J. C., & Liu, W. F. (2010). *Simultaneous temperature and pressure measurement using a packaged FBG and LPG.* Paper presented at the 15th Optoelectronics and Communications Conference, Sapporo, Japan.

Wang, Z., Shen, F., Song, L., Wang, X., & Wang, A. (2007). Multiplexed fiber Fabry-Perot interferometer sensors based on ultrashort Bragg gratings. *IEEE Photonics Technology Letters*, 19(8), 622–624.

Webb, D. J. (2015). Fibre Bragg grating sensors in polymer optical fibres. *Measurement Science and Technology*, 26(9), 092004–092015.

Wei, T., Han, Y., Li, Y., Tsai, H. L., & Xiao, H. (2008a). Temperature-insensitive miniaturized fiber inline Fabry-Perot interferometer for highly sensitive refractive index measurement. *Optics Express*, 16(8), 5764–5769.

Wei, T., Qiao, X. G., & Jia, Z. A. (2011). Simultaneous sensing of displacement and temperature with a single FBG. *Optoelectronics Letters*, 7(1), 26–29.

Wei, Z., Song, D., Zhao, Q., & Cui, H. L. (2008b). High pressure sensor based on fiber Bragg grating and carbon fiber laminated composite. *IEEE Sensors Journal*, 8(10), 1615–1619.

Wild, G., & Hinckley, S. (2010). *Optical fibre Bragg gratings for acoustic sensors*. Paper presented at the Proceedings of 20th International Congress on Acoustics, Sydney, Australia.

Woyessa, G., Nielsen, K., Stefani, A., Markos, C., & Bang, O. (2016). Temperature insensitive hysteresis free highly sensitive polymer optical fiber Bragg grating humidity sensor. *Optics Express*, 24(2), 1206–1213.

Woyessa, G., Pedersen, J. K. M., Fasano, A., Nielsen, K., Markos, C., Rasmussen, H. K., & Bang, O. (2017). Zeonex-PMMA microstructured polymer optical FBGs for simultaneous humidity and temperature sensing. *Optics Letters*, 42(6), 1161–1164.

Wu, C., Fu, H. Y., Qureshi, K. K., Guan, B. O., & Tam, H. Y. (2011). High-pressure and high-temperature characteristics of a Fabry-Perot interferometer based on photonic crystal fiber. *Optics Letters*, 36(3), 412–414.

Wu, Q., Okabe, Y., & Yu, F. (2018). Ultrasonic structural health monitoring using fiber Bragg grating. *Sensors*, 18(10), 3395–3421.

Xu, B., Liu, Y. M., Wang, D. N., & Li, J. Q. (2016). Fiber Fabry-Perot interferometer for measurement of gas pressure and temperature. *Journal of Lightwave Technology*, 34(21), 4920–4925.

Xu, M., Shi, S., Zhang, T., & Yang, H. (2019). Research on the elastic-optical coefficient of fiber-optic and the experimental measurement by fiber Bragg grating. *Optik*, 195, 163159–163165.

Xu, M. G., Reekie, L., Chow, Y. T., & Dakin, J. P. (1993). Optical in-fibre grating high pressure sensor. *Electronics Letters*, 29(4), 398–399.

Xue, H., Xu, Z., Chen, H., Yang, Y., You, J., Yan, J., Fu, H., & Zhang, D. (2015). Continuous liquid level sensor based on a reflective long period fiber grating interferometer. *Measurement Science and Technology*, 26(3), 037001–037005.

Yao, J. L., Yang, X., Shao, N., Luo, H., Zhang, T., & Jiang, W. G. (2016). A flexible and highly sensitive piezoresistive pressure sensor based on micropatterned films coated with carbon nanotubes. *Journal of Nanomaterials*, 2016, 1–5.

Yu, Y., Chen, X., Huang, Q., Du, C., Ruan, S., & Wei, H. (2015). Enhancing the pressure sensitivity of a Fabry-Perot interferometer using a simplified hollow-core photonic crystal fiber with a microchannel. *Applied Physics B*, 120(3), 461–467.

Zhang, W., Li, F., & Liu, Y. (2009). FBG pressure sensor based on the double shell cylinder with temperature compensation. *Measurement*, 42(3), 408–411.

Zhang, X., Alemohammad, H., & Toyserkani, E. (2013a). Sensitivity alteration of fiber Bragg grating sensors with additive micro-scale bi-material coatings. *Measurement Science and Technology*, 24(2), 025106–025116.

Zhang, Y., Chen, X., Wang, Y., Cooper, K. L., & Wang, A. (2007). Microgap multicavity Fabry-Perot biosensor. *Journal of Lightwave Technology*, 25(7), 1797–1804.

Zhang, Y., Yuan, L., Lan, X., Kaur, A., Huang, J., & Xiao, H. (2013b). High-temperature fiber-optic Fabry-Perot interferometric pressure sensor fabricated by femtosecond laser. *Optics Letters*, 38(22), 4609–4612.

Zhang, Y., Zhang, J., & Zheng, Y. (2017). The thermal expansion behaviour of carbon fiber-reinforced resin mineral composite postcured under various temperatures. *Journal of Reinforced Plastics and Composites*, 36(7), 505–518.

Zhao, J. R., Huang, X. G., He, W. X., & Chen, J. H. (2010). High-resolution and temperature-insensitive fiber optic refractive index sensor based on Fresnel reflection modulated by Fabry-Perot interference. *Journal of Lightwave Technology*, 28(19), 2799–2803.

Zhao, Y., Yu, C., & Liao, Y. (2004). Differential FBG sensor for temperature-compensated high-pressure (or displacement) measurement. *Optics & Laser Technology*, 36(1), 39–42.

Zhao, Z. G., Zhang, Y. J., Li, C., Wan, Z., Li, Y. N., Wang, K., & Xu, J. F. (2015). Monitoring of coal mine roadway roof separation based on fiber Bragg grating displacement sensors. *International Journal of Rock Mechanics and Mining Sciences*, 74, 128–132.

Zheng, S., & Zhang, X. (2005). *Simultaneous measurement of pressure and temperature using a single fiber Bragg grating.* Paper presented at the 2005 Progress in Electromagnetics Research Symposium, Hangzhou, China.

Zhong, C., Shen, C. Y., Chu, J. L., Zou, X., Li, K., Jin, Y. X., & Wang, J. F. (2011). A displacement sensor based on a temperature-insensitive double trapezoidal structure with fiber Bragg grating. *IEEE Sensors Journal*, 12(5), 1280–1283.

Zhou, K., Zhang, L., Chen, X., & Bennion, I. (2006). Optic sensors of high refractive-index responsivity and low thermal cross sensitivity that use fiber Bragg gratings of >80° tilted structures. *Optics Letters*, 31(9), 1193–1195.

Zhou, W., Dong, X., Ni, K., Chan, C. C., & Shum, P. (2010). Temperature-insensitive accelerometer based on a strain-chirped FBG. *Sensors and Actuators A: Physical*, 157(1), 15–18.

Zhu, S. E., Ghatkesar, M. K., Zhang, C., & Janssen, G. C. A. M. (2013). Graphene based piezoresistive pressure sensor. *Applied Physics Letters*, 102(16), 161904–161907.

Zhu, Y., Shum, P., Lu, C., Lacquet, B. M., Swart, P. L., & Spammer, S. J. (2003). Temperature-insensitive fiber Bragg grating accelerometer. *IEEE Photonics Technology Letters*, 15(10), 1437–1439.