Extended Abstracts of the 2016 International Conference on Solid State Devices and Materials, Tsukuba, 2016, pp795-796

PS-7-05

High Sensitivity Flexible Metal-Insulator-Metal Localized Surface Plasmon Resonance Sensors on PDMS Substrate

Hsiang-Ting Lin[1,2], Chiao-Yun Chang[1], Shih-Wei Haung[1], Teng-Yi Shieh[1,2], Min-Hsiung Shih[1,2,3]

[1] Academia Sinica
Research Center of Applied Sciences (RCAS)
Taipei, 11529, Taiwan
Phone: +886-2-2787-3184 E-mail: mhshih@gate.sinica.edu.tw
[2] National Chiao-Tung University
Department of Photonics
Hsinchu 30010, Taiwan
[3]National Sun Yat-sen University
Department of Photonics
Kaohsiung 804, Taiwan

Abstract

In this study, a flexible localized surface plasmon resonance (LSPR) index sensor was demonstrated with metal-insulator-metal (MIM) nanodisk structure embedded in the PDMS substrate. The high sensitivity of 2345nm/RIU was obtained from the oval-shaped nanodisk sensor structure, and its sensitivity maintaining stable as the variation less than 10% under the different bending curvatures.

1. Introduction

Localized surface plasmon resonance (LSPR) is light induced conduction electron oscillation which is localized and resonated with certain frequency of light. Since the conduction electron oscillation frequency is depending on external dielectric constant ϵ, the optical properties of LSPR is sensitive to the ϵ related environment refractive index.[1] Therefore, LSPR devices are good choice for applying as refractive index sensors. One attractive structure is LSPR based metal-insulator-metal (MIM) sensors which benefit to the wide angular, broadband absorption and tunable LSPR wavelength through manipulating the device geometry have been demonstrated as refractive sensor.[1, 2]

Recently, polymer substrate flexible devices are more and more popular. Due to the high flexibility, transparency and low cost of polymer, there are wide range of applications including sensing. When applying sensor on polymer substrate, it is more suitable for biomedical usage such as integrating with wearable devices and *in vitro* diagnostics. A sensor which is flexible means it can sustain deformation and still working. There is no doubt that keeping stable sensitivity under deformation is a critical issue for flexible sensors.[3]

Herein, we experimentally demonstrate a flexible MIM refractive index sensor on polymer substrate polydimethylsiloxane (PDMS) with high sensitivity and high sensing stability even under substrate bending. We optimized the geometry of the MIM sensor to achieve higher sensitivity and better figure-of-merit (FOM). The sensitivity of the flexible MIM sensor under different bending conditions was also characterized to ensure the high stable performance of our flexible MIM sensor.

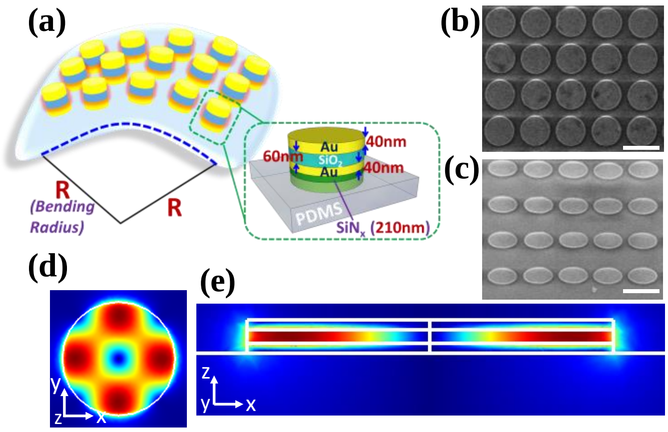

Fig. 1 (a) The schematic diagram of the flexible MIM sensor. The inset describes the layer structure of the sensor. The SEM pictures of (b) circular(b/a=1.0) (c) oval(b/a=0.6) MIM disk. The scale bar are both 2μm. (d) Top and (e) cross section view of the mode profile of normalized magnetic field for the flexible MIM sensor.

2. Experiment

Fig. 1(a) shows the schematic diagram of the LSPR MIM nanodisk sensor embedded in the flexible PDMS substrate. The MIM LSPR nanodisk is composed of a 60nm SiO_2 layer sandwiched between two 40nm Au disks. And there are not only circular disks but also oval disks with different long/short-axis length ratio in the flexible MIM sensors as Fig. 1(b), (c) presented.

Since the flexibility and non-conductivity of PDMS, it is difficult to define the device pattern through normal electron-beam lithography (EBL). In this experiment, we demonstrate a “transfer” process for the flexible MIM sensor fabrication. First, the MIM layer and 210nm SiN_x was deposited on InP sacrificed substrate. Next, standard EBL followed by dry etching forming the SiN_x hard mask. Then, we using Ar ion-milling to fabricate the MIM disks. After removing the resist residue, a poly(methyl methacrylate) (PMMA) layer was

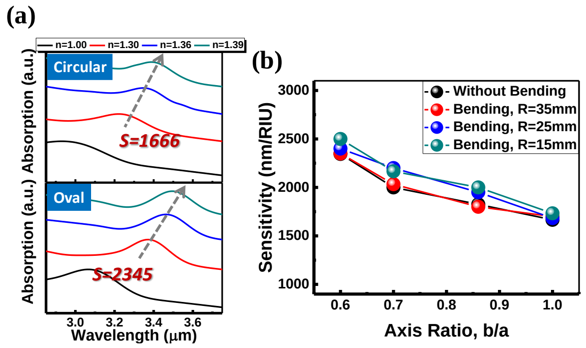

Fig. 2 (a) The absorption spectrum of the circular (b/a=1.0) and oval (b/a=0.6) flexible MIM sensor under environment n change. (b) The sensitivity of different shape flexible MIM sensor under bending. The bending curvature is defined as 1/R.

coated and partially etched as a spacer layer to prevent the MIM disks sinking in PDMS. Then the whole sample bonding upside down to the unglued PDMS and wet etched the InP and PMMA. Finally, the MIM disks were transferred from InP to PDMS and ready for testing.

For characterizing the sensing properties of our flexible MIM sensors, a Fourier transform infrared spectroscopy (FTIR) system with microscope was applied to measure the corresponding absorption spectrum varying the ambience refractive index. The sensitivity value was obtained by analyzing the spectrums. To further investigate the sensing stability of the flexible MIM sensors, we fixed the sensors on a curved mold with different bending curvature and repeated above measurement. Due to PDMS substrate is highly flexible, the flexible MIM sensor is bended as the same bending curvature as the curved mold. Thus the sensing stability of our flexible MIM sensor under bending was tested through comparing the sensitivity variation.

3. Results and Discussion

The LSPR properties of the MIM disk structure was simulated by utilizing the finite-element method (FEM) and the normalized magnetic field mode profile was shows in Fig. 1(d)(e). Because the surface plasmon polaritons of top and bottom Au disk couple and resonate in the SiO_2 layer, the LSPR mode is mainly confined in this region. However, there is still some field leaking out of SiO_2 causing the LSPR mode of MIM disk is sensitive to the environment refractive index variation.

From our previous research, turning a MIM circular disk into oval shape will break the geometry symmetry and increase the mode leakage. Based on this concept we fabricated a series of flexible MIM disk sensor in oval shape varying the long(a) and short(b)-axis length with b/a ratio from 0.6 to 1.0 (circular disk). We applied these sensors on the refractive index (n) sensitivity measurement as mention previously with environment n=1.30, 1.36, 1.39. Fig. 2(a) shows the absorption spectrum of the MIM circular disk(b/a =1.0) and oval disk (b/a=0.6). We can observe that the absorption peak shift is more obvious for b/a=0.6 oval disk, which means higher sensitivity $S = \Delta\lambda/\Delta n$. We plot all the S value varying b/a in the black line in Fig. 2(b). It show the sensitivity increased along with decreasing b/a, that indicate that breaking the geometry symmetry of circular disk will improve the sensor sensitivity.

On the other hand, although integrating sensors with flexible substrate bring the whole devices sustaining deformation to a certain extent, for the sensing stability is a different thing. Consequently, whether our flexible MIM sensor maintain stable sensitivity or not during deformation is the key point we should investigate. The bending was created on our flexible MIM sensor through fixing it on the curved mold as mention earlier. The bending curvature is quantized by the bend radius R of the curved mold. In this experiment, we set R as 35mm, 25mm and 15mm and repeat the sensitivity measurement. The sensitivity of different flexible MIM sensor under bending is presented in Fig. 2(b). It can be observed that the sensitivity remain almost the same value under bending.

And we also calculate the corresponding sensitivity variation comparing with the non-bending case to further investigate the stability of our sensor. It should be point out that all the sensitivity variation are less than 10% which means our flexible MIM sensor is very stable sustaining bending deformation. Such stability can be explained that our flexible MIM sensor sensing through the LSPR of individual MIM disk which can be verified by the mode profile in Fig. 1(d) (e). When applying bending on the sensor, it is similar to just rearrange the MIM disks. Therefore, the LSPR mode was not change as a result of the stable sensitivity under bending.

4. Conclusions

In conclusion, a flexible MIM refractive index sensor on PDMS with high sensitivity was demonstrated through the transfer process. The high sensitivity is maintained as the variation less than 10% even under the sensor bending with 35 mm bending radius. The high sensitivity is achieved through tuning the geometry of the MIM sensor. The LSPR nature properties help to maintain the sensing stability which was also characterized by the sensitivity variation under the different bending curvatures. The high sensitivity and environmental stability of the flexible LSPR sensor ensure that it could be a reliable sensing device for index-sensing and biodetection applications.

Acknowledgements

The study is supported by the funding from the Minister of Science and Technology (MOST), Taiwan ROC under contract No. NSC 102-2112-M-001-019-MY3

References

[1] J. Cao, T. Sun, K.T.V. Grattan, Sensors and Actuators B: Chemical, 195 (2014) 332-351.
[2] N. Liu, M. Mesch, T. Weiss, M. Hentschel, H. Giessen, Nano Lett, 10 (2010) 2342-2348.
[3] C. Pang, C. Lee, K.-Y. Suh, Journal of Applied Polymer Science, 130 (2013) 1429-1441.