Highly flexible and sensitive graphene–silver nanocomposite strain sensor

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Abstract— **We are reporting, a novel reduced graphene oxide (RGO) and silver (Ag) nanocomposite based piezoresistive thin film sensor realized on kapton (polyimide) membrane substrate by drop casting method for strain sensing application. Incorporation of small quantity of (Ag) fillers into RGO, subsequently it can create a novel nanocomposite with improved structural and functional properties. The as-synthesized RGO and nanocomposite were characterized using X-ray diffraction (XRD), field emission- scanning electron microscope (FE-SEM) for their structural properties and morphology analysis. As fabricated nanocomposite strain sensor undergoes piezoresistive behavior when mechanical strain is applied to the flexible substrate and its output resistance variations have been observed. The electromechanical property of nanocomposite was analyzed with mechanical cantilever bending method and the gauge factor of about 9 to 12 was observed. The change of electrical resistance of the nanocomposite film can be used in sensing mechanism for changes in chemical, biological, vibrational, temperature, pressure, load or force and displacement sensor applications.**

Keywords: RGO nanosheets; Ag nanoparticles; nanocomposite; strain sensor; piezoresistivity

I. INTRODUCTION

Strain sensor requirements have played an interesting role for several decades in the research community. The strain sensors can measure the local deformation or structural changes occurring in the surrounding infrastructure as well as internal activities of moving objects [1]. Researchers are looking for the efficient materials which can exhibit large structural changes due to applied strain and are focused on nano scale materials at low cost [1-5].

Recently, graphene and graphene-based nanocomposite materials have attracted in the realization of the nanocomposite strain sensors due to their chemical and physical properties. The graphene is one of the carbon classes of two dimensional (2D) single-atom thick sheets of sp^2 bonded carbon atoms that are arranged in a perfect honeycomb lattice. Moreover, the graphene posses a number of unique and exceptional functional properties such as structural, optical, thermal, mechanical and electrical [2].Therefore, the graphene is the most intensive currently studied material for a wide range of applications in electronic, energy, and sensing fields [3]. Lee *et al*. [4] have reported on the piezoresistive response of graphene for strain sensor with a gauge factor of 6.1. Fu *et al*. [5] also reported a monolayer graphene based strain sensor with high sensitivity. Further, Wang *et al*. [6] showed that graphene can be used under high strain over 30% using flexible structural geometry. However, the presently available traditional strain gauge sensors have fixed directional property, low resolution at nano scale and it is not possible to integrate with the structural materials [8]. In addition to the above, recently flexibility is one of the most important factors that have become a great challenge for the development of human interface electronics for the strain sensing [9].

According to the literature, the applications of graphene based strain sensors have not been explored in many practical and industrial applications. Also, the nanocomposite with graphene-metal based strain sensors are not yet attempted. Therefore, the present work is carried out by synthesizing the metal nanocomposite with graphene. These are embedded to form a good material for the strain sensor on the flexible substrate which can exhibit high resolution and Gauge factor (G.F) at nano scale. The graphene based metal nanocomposite material is able to sense small deformations even in response to very low applied pressure or force. The excellent stretchablity and good flexibility of graphene provides a new path to demonstrate strain sensor devices in real life applications.

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II. EXPERIMENTAL

A. Preparation of RGO

The reduced graphene oxide (RGO) was synthesized from graphene oxide (GO) through the chemical reduction process by modified Hummers method. As prepared GO (0.3 g; 1 mgml^{-1}) was dissolved in 300 ml of deionized water through ultrasonication for 2 hours. Hydrazine hydrate solution was added to the mixture under constant stirring at 95°C for the duration of 4 hours. The prepared RGO solution was filtered with filter paper to separate the unreacted components from the mixture. Finally the sample was dried up at 80°C for 2 hours.

B. Preparation of RGO – Ag nanocomposite

The RGO-Ag nanoparticles composite was prepared by dispersing RGO nanosheets and Ag nanoparticles in an N-Methyl-2-pyrrolidone (NMP) solution at weight ratio of 0.05:0.1. The mixed solution was ultra sonicated for about 1hour in order to achieve a homogenous dispersion of RGO and Ag nanoparticles.

C. Fabrication of RGO- Ag nanocomposite strain sensor

The micro mold structure pattern was made with stainless steel sheet of thickness 50 microns. The developed mechanical mask was used to obtain patterns of RGO-Ag nanocomposite solution on flexible kapton substrate by drop casting method. Subsequently, the RGO-Ag nanocomposite sensing film material was dried at 80°C for 1hour. This resulted in removal of the solvent and rearrangement of the atoms in the nanocomposite. Thin double enameled copper wires attached on top of the nanocomposite pattern using silver paste. After this, the sample (strain sensor) was dried again at 90°C for 30 minutes for the purpose of curing of the electrical contacts and making the device robust.

III. RESULTS AND DISCUSSIONS

A. Crystal structure analysis by XRD

X-ray diffraction (XRD) patterns were recorded for the synthesized RGO and RGO-Ag nanocomposite for their crystalline structures. The XRD pattern revealed the existence of a broad peak at 2θ =25.61° corresponding to the (002) plane of RGO as shown in Fig.1. The crystal structure of silver coated (decorated) RGO nanocomposite peak at 38.2° indicate the corresponding plane of (111) face centered cubic (FCC) Ag nanoparticles. The other peaks at 44.57°, 64.7°, 77.64° and 81.91° indicates the corresponding planes of (111), (200), (220) and (311) respectively. There is no other intensity peak observed related to RGO in the RGO-Ag nanocomposite due to the small amount of the RGO. However, the appearance of high intensity peaks corresponding to Ag nanoparticles can be seen clearly.

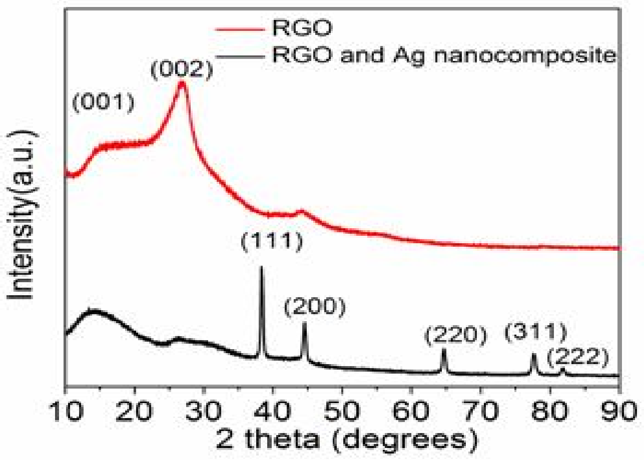

Figure.1: XRD patten of RGO and RGO-Ag nanocomposite

B. Surface morphology analysis by FE-SEM

The surface morphology analysis of as-synthesized RGO and RGO-Ag nanocomposite was examined using field emission-scanning electron microscopy (FE-SEM (Carl Zeiss), ULTRA 55). Fig.2 shows the surface morphology of the prepared RGO, confirming a loosely bound sheet like structure. The distribution of Ag nanoparticles and intercalation with RGO in the prepared composite can be clearly seen in Fig.3. The presence of RGO prevents the agglomeration and distributes the Ag nanoparticles. The homogeneous distribution of Ag nanoparticles and intercalated RGO nanosheets are expected for the improved electrical performance of the nanocomposite. The presence of Ag in the RGO nanocomposite plays an important role such as a dispersing agent, reinforcement and formation of conduction path between the RGO nanosheets, for their enhanced piezoresistive property.

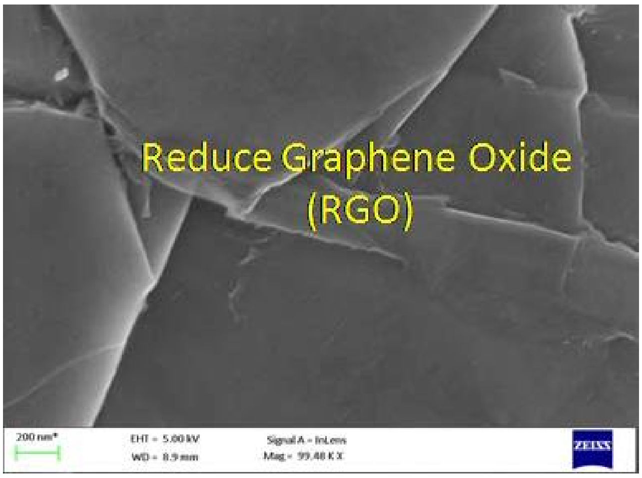

Figure.2: FE-SEM image of RGO nanosheets

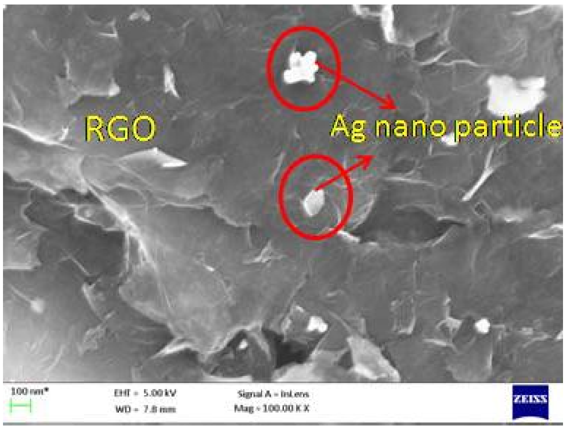

Figure 3: FE-SEM image of RGO-Ag nanocomposite (the dispersed Ag nanoparticles with RGO nanosheets)

C. Performance of fabricated nanocomposite strain sensor

The schematic view and the photograph of the fabricated piezoresistive nanocomposite thin film strain sensor are shown in Fig. 4 and Fig.5 respectively. The active area of the device is around 4 mm x 1 mm. In order to study the performance of the device (strain sensor), it was fixed in cantilever configuration as shown Fig. 6. As can be observed, the kapton cantilever (40 mm x 10 mm x 0.175 mm) was subjected to bending by applying the force at its free end using a digital height gauge.

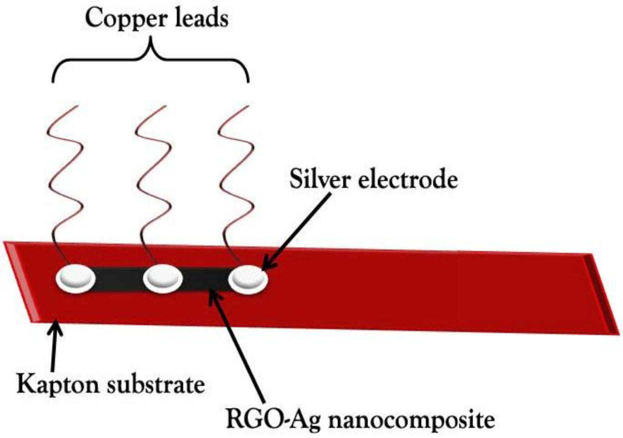

Figure. 4: Schematic diagram of nanocomposite strain sensor

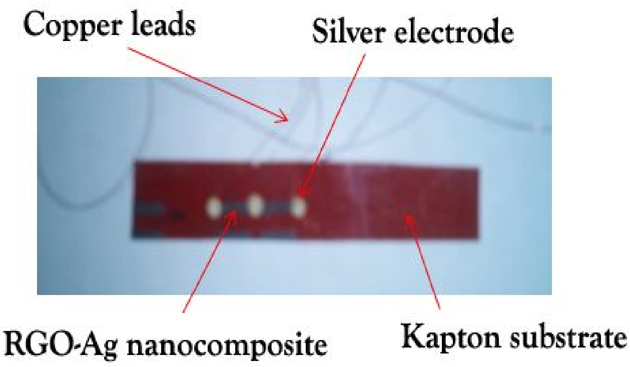

Figure. 5: Fabricated nanocomposite strain sensor on flexible kapton substrate

The photograph of the complete experimental set up used is shown in Fig.6.The electrical leads of the strain sensor were connected to 6 ½ digitalmultimeter (Gwinstek GDM-8261). The sensor was subjected to strain by applying the force at the free end of the cantilever. The deflection of the free end of the cantilever was measured using the digital height gauge and the corresponding resistance variation of the gauge was noted from the digital multimeter. Fig.7 shows the variation of the relative change resistance ($\Delta R/R$) with strain (ε) for the nanocomposite strain sensor. The variations were noted in both ascending and descending order.

The sensitivity/gauge factor of the strain sensor was calculated using the following equation [4]

$$G.F = (\Delta R/R)/\varepsilon \text{ .... } (1)$$

Where ε is the strain experienced by the strain sensor, ΔR the change in resistance and R the initial resistance of the sensor.

The strain experienced by the sensor was calculated by using the following equation [7]

$$\varepsilon = \frac{3yhx}{2l^3} \text{ .... } (2)$$

Where y is the deflection at the free end, l is the length of the cantilever beam, x is the distance from centre of strain gauge to the point of application of load and h is the thickness of the beam.

As can be seen in Fig.7, the variations are linear. The calculated gauge was found to be in the range of 9 to 12 which is better compared to the already reported values for the graphene strain sensor [8].

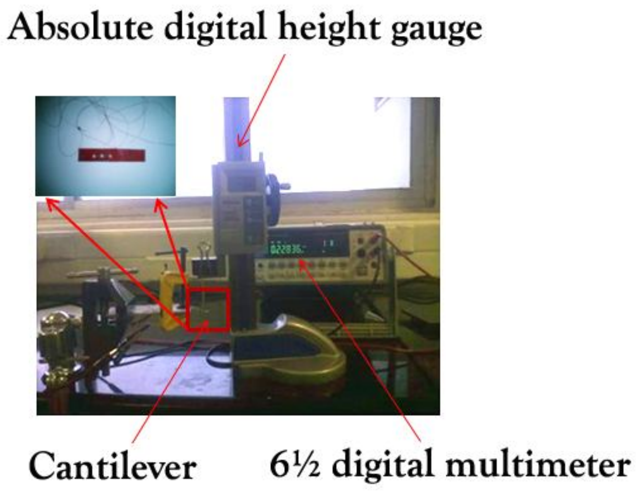

Figure.6: Cantilever bending set up with absolute digital height gauge

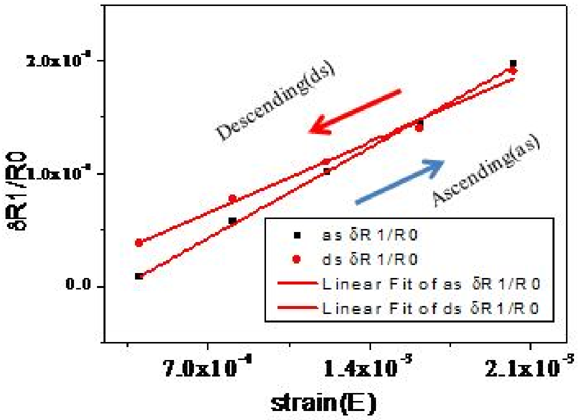

Figure .7: Response of the nanocomposite strain sensor varies relative resistance change with strain

IV. CONCLUSION

The piezoresistive nanocomposite based strain sensor was realized using RGO and Ag nanoparticles. The RGO nanosheets were successfully synthesized by using modified Hummers method. The homogeneous RGO-Ag nanocomposite was prepared through ultrasonication for the realization of strain sensor. The fabricated nanocomposite strain sensor exhibits a gauge factor of about 9 to 12, which is better than the reported value for graphene based strain sensor. The advantages of the fabricated nanocomposite strain sensor are (i) the process of fabrication is simple & inexpensive; (ii) mass production on large area possible; (iii) the materials used are nontoxic & biocompatible. The phenomena of change in electrical resistance of the nanocomposite film can also be used for detecting other parameters involved in chemical, biological and vibrational, sensor applications.

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REFERENCES

[1].Sang-Hoon Bae, Youngbin Lee, BhupendraK.Sharma, Hak-joo Lee, Jae-hyunKim,Jong-Hyun Ahn," Graphene based transparent strain sensor", carbon, 2013, 51, 236-242.

[2]. Geim AK and Novoselov KS," The rise of graphene",Nature materials,2007,6,183-191.

[3]. Novoselov KS , Falko VI , Colombo L, Gellert PR , Schwab MG and Kim K," A roadmap for graphene", Nature, 2012, 490, 192-200.

[4]. Youngbin Lee, Sukang Bae, Houk Jang, Sukjae Jang, Shou-En Zhu,Sung Hyun Sim, Young Il Song, Byung Hee Hong, and Jong-Hyun Ahn ,"Wafer-Scale Synthesis and Transfer of Graphene Films" , Nano letters, 2010, 10, 490-493.

[5]. Zhao Jing , Zhang Guang-Yu and Shi Dong-Xia "Review of graphene-based strain sensors", chin.phys.B, 2013 , 22, 057701(1-9).

[6]. Yi Wang,Rong Yang, Zhiwen Shi, Lianchang Zhang,Dongxia Shi,Enge Wang and Guangyu Zhang ,"Super-Elastic Graphene Ripples for Flexible Strain Sensors,"ACS Nano , 2011, 5, 3645-3650.

[7]. Lecture notes "Introduction to strain gauge based measurement systems" http://faculty.uml.edu/pavitabile/22.302/web_download/Strain_Gage_Lab5_010505.pdf.

[8]. Xiao Li ,Rujing Zhang, Wenjian Yu, jinquan Wei, Dehai Wu, Anyuan Cao, Zhihong Li , Yao Cheng, QuanshuiZheng, Rodney S.Ruoff and Hongwei Zhu," Stretchable and highly sensitive graphene on polymer strain sensors" Nature Scientific Reports, 2012, vol 2, 870.

[9]. John A. Rogers,Takao Someya and Yonggang Huang ," Materials and Mechanics for Stretchable Electronics", Science, 2010, 327, 1603-1607.