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Forming of silver nano-ribbons with ultrasonic pressure process

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ABSTRACT

Silver nano-ribbons were obtained with plastically deforming of silver nanowires by ultrasonic pressure process with different flattening degrees on polyethylene terephthalate. The degree of flatting was decided on the value of input energy which is the product of the press value and press time. Atomic force microscope was used to investigate the hardness of silver nano-ribbons. It was verified that Ag nano-ribbons exhibited the same work-hardening phenomenon of macroscopically silver material during the process of flatting.

1. Introduction

With increasing interest in silver (Ag) nanomaterials in different fields, such as transparent flexible conductive screens, solar electrodes, and nano-biosensors, the most researched morpholgy of silver nano materials is nano wires [1,2]. As a flexible metal material, conventional metallic silver can be easily deformed for shaping and the hardness of the silver can be enhanced due to the mechanism of work hardening. At the nanoscale level, mechanical properties can deviate from those of the non-nanoscale materials and often exhibit a strong dependence on the object's size and shape [3,4]. With the increase of deformation of nano silver wire can obtain harder and flatter silver nano-belt theoretically. However, there is no report about the deformation and the hardness of this nano silver material with supersonic pressure process yet. Ultrasonic pressure processing is used in welding of polymers and metals. Under the joint action of the pressure and the ultrasonic wave, the contact surface between the workpiece and the mold may be relatively slightly slipped with high frequency, thereby activating the viscoelastic heat. It can reach the recrystallization temperature of "silver nanowires" instantly. Due to the melting point reduction phenomenon of the nano material, the silver nano material can be plastically deformed like hot metal forging [5–7].

In this paper, ultrasonic pressure processing is employed to obtain flat nano-silver belts with different degree of flattening of cylinder Ag nanowires. The silver nano-ribbons were subjected to force-distance curve test with atomic force microscope to invest the change of the hardness [8,9].

2. Experiment

2.1. Preparation

Silver nanowires with diameters of 45–50 nm and lengths of 15–25 μm were synthesized by the polyol reduction method [10,11]. The Ag nanowires were spin-coated on a $4 \times 4\text{-cm}^2$ polyethylene terephthalate (PET) substrate, and were subjected to a deformation process using precision ultrasound equipment. The control parameters of the device were mainly the ultrasonic time and the pressure of the pressure head, and the pressure head was automatically lifted when the sounding time ended. The pressures of the indenter selected in this experiment were 0.1–0.3 MPa, corresponding to the ultrasonic times under different pressures of 0.1–1.2 s and the ultrasonic power was 20 kHZ. The experimental ultrasonic probe size is $3.5 \times 2.5\text{-cm}^2$, which can be adjusted according to the actual application. The Silver nanowires were processed with ultrasonic processing to obtain flattened Ag nano-ribbons as shown in Fig. 1.

2.2. Characterization

In this paper, thermal field emission scanning electron microscopy (SEM) (SU-70, Hitachi Co., Ltd. Japan) was used to realize micro-characterization of the processed Ag nano-ribbons. The force-distance curve test was conducted on the Ag nano-ribbons using an atomic force microscope (Dimension ICON, Bruker,

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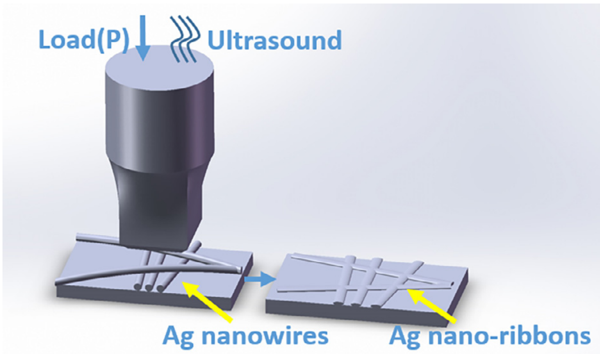

Fig. 1. Ultrasonic processing for forming Ag nano-ribbons.

Germany). In the AFM F-D curve test, the relationship between the force and the sample shape variable can be obtained by fitting calculation to obtain the modulus value of the sample, which is often used to reflect the softness and hardness of the samples [8,9]. NanoScope® Analysis version 1.5 software (Bruker, Germany) was used to calculate the change in hardness of the Ag nano-ribbons.

3. Results and discussion

The Ag nanowires without processing deformation are shown in Fig. 2a. The deformed silver nanowires with different ultrasonic pressure processing parameters are shown in Fig. 2b and c. The cylindrical nanowires were obviously deformed and became flat nano-ribbons after the process of Ultra-sonic pressing.

The average width of the Ag nanowires and nano-ribbons calculated of 20 selected samples and linear fit result with the processing parameters are plotted shown in Fig. 2d. The fitting results show that the Ag nano-belt width increases linearly with press time in different pressure in this experiment. The ration of the slopes of the lines of press 0.1, 0.2 and 0.3 Mpa near to 1:2:3 which equal to the ratio of press values. The product of the press value and press time is regarded as the "Input Energy". The larger the input energy is applied, the wider the deformation of Ag nano-ribbons are obtained. When the input energy is the same, the deformation is also same.

AFM was used to characterize the changes in flatness of Ag nano-ribbons. Fig. 3.a shows the roughness of PET with Ag nano-ribbons. With the increasing of input energy, the roughness of the PET surface decreased obviously due to the flattening of the silver nanowires. Fig. 3.b shows the micro-hardness of unflattened Ag nanowires. There were two parts in the figure: high modulus for Ag nanowires of about 9–12 GPa and low modulus parts for PET matrix. Fig. 3.c shows the micro-hardness of silver nano-ribbons with input energy: 0.36 MPa.S, the Ag nano-ribbons modulus value distribution from about 25–30 GPa which is much higher than the silver nanowires. 100 points of nano silver material under the input energy of 0, 0.18 and 0.36 Mpa.S were taken and plotted as a scatter plot in Fig. 3.d. The average hardness of the three cases were calculated to be: 11 GPa, 16 GPa and 30 GPa. From the statistical analysis, the degree of flattening of Ag nano-ribbons hardness

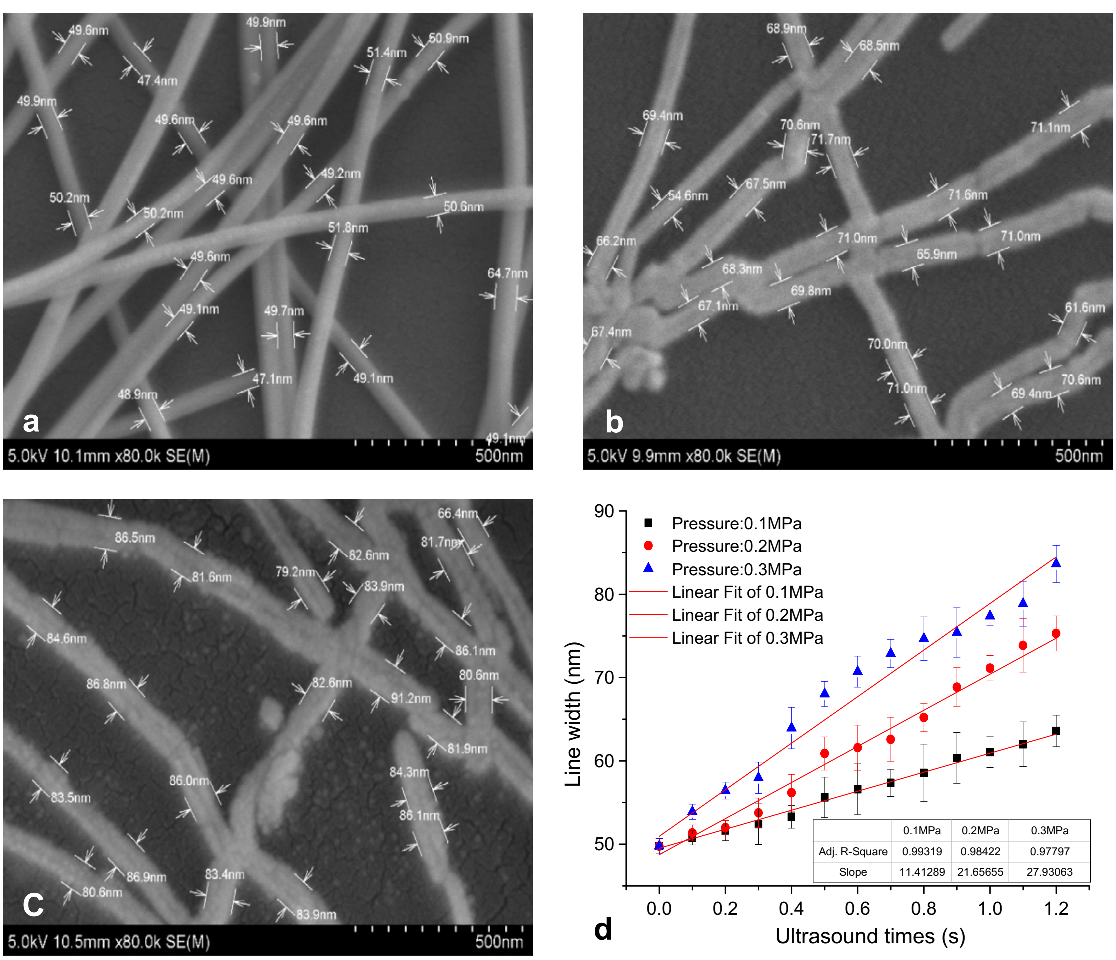

Fig. 2. Different degrees of deformation of Ag nano-belt SEM and size statistics: a, non-deformation; b, 0.2 MPa and 0.9 s; c, 0.3 MPa and 1.2 s.

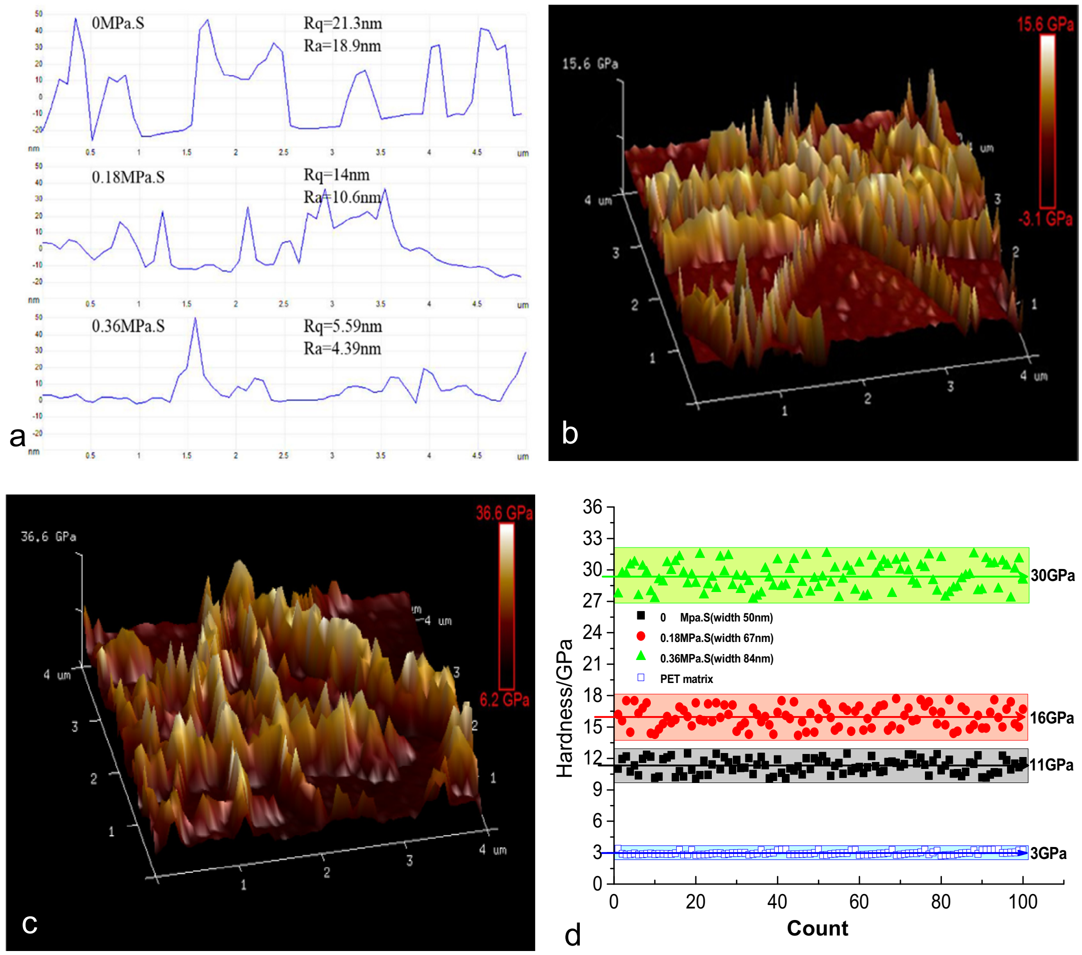

Fig. 3. Roughness and hardness modulus of Ag nano-ribbons with different input energy: a, Roughness of PET surface [12]; b, 0Mpa.S; c, 0.36Mpa.S; d, Statistics of hardness modulus.

distribution was determined, and with increasing degree of flattening, the hardness also increased. So silver nano-ribbons also exhibits work hardening phenomenon like macroscopically conventional metallic silver.

4. Conclusions

Through the use of ultrasonic pressure processing, Ag nanowires can be uniformly deformed to form Ag nano-belt. Precise control of the process parameters enables the Ag nanowires to linearly extend in the radial direction to obtain different degrees of flattening. The deformation is decided by the input energy which is the product of the press value and treet time.

Silver nano-ribbons also exhibits work hardening phenomenon like macroscopically silver material during the process of flattening.

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Declarations of interest

None.

References

[1] J.Y. Jung, N. Qaiser, G. Feng, B.-I. Hwang, T. Kim, J.H. Kim, S.M. Han, Size-dependent hardness of five-fold twin structured Ag nanowires, Phys. Chem. Chem. Phys. 19 (2017) 1311–1319, https://doi.org/10.1039/C6CP07424C.
[2] B. Hwang, H.A. Shin, T. Kim, Y.C. Joo, S.M. Han, Highly reliable Ag nanowire flexible transparent electrode with mechanically welded junctions, Small 10 (2014) 3397–3404, https://doi.org/10.1002/smll.201303906.
[3] G. Stan, C.V. Ciobanu, P.M. Parthangal, R.F. Cook, Diameter-dependent radial and tangential elastic moduli of ZnO nanowires, Nano Lett. 7 (2007) 3691–3697, https://doi.org/10.1021/nl071986e.
[4] Y.-J. Choi, I.-S. Hwang, J.-G. Park, K.J. Choi, J.-H. Park, J.-H. Lee, Novel fabrication of an SnO2 nanowire gas sensor with high sensitivity, Nanotechnology 19 (2008), https://doi.org/10.1088/0957-4484/19/9/095508 095508.
[5] Z.B. Zhang, X.D. Wang, Y. Luo, Y.S. Zheng, Y.G. Zhang, L.D. Wang, Ultrasonic plastic welding mechanism, Trans China Welding Inst 11 (2010) 0253–360X.
[6] Z.Q. Zhang, Z.B. Zhang, Y. Luo, X.D. Wang, L.D. Wang, Simulation calculation of viscoelastic heat of ultrasonic plastic welding, Trans. China Weld. Inst. 09 (2009), 97-100+118.
[7] S. Elangovan, S. Semeer, K. Prakasan, Temperature and stress distribution in ultrasonic metal welding-An FEA-based study, J. Mater. Process. Tech. 209 (2009) 1143–1150.
[8] H.J. Butt, B. Cappella, M. Kappl, Force measurements with the atomic force microscope: technique, interpretation and applications, Surf. Sci. Rep. 59 (2005) 1–152.
[9] Y.W. Bao, W. Wang, Y.C. Zhou, Investigation of the relationship between elastic modulus and hardness based on depth-sensing indentation measurements, Acta Materialia 52 (2004) 5397–5404.
[10] X.S. Li, X.Z. Xiang, L. Wang, Conductivity and mechanical properties of conductive adhesive with silver nanowires, Rare Metals 3 (2018) 1–5.
[11] X.Z. Xiang, W.Y. Gong, M.S. Kuang, L. Wang, Progress in application and preparation of silver nanowires, Rare Metals 35 (2016) 289–298.
[12] E. Yousefi, M.R. Ghadimi, S. Amirpoor, A. Dolati, Preparation of new superhydrophobic and highly oleophobic polyurethanecoating with enhanced mechanical durability, Appl. Surf. Sci. 454 (2018) 201–209.