Molecular Crystals and Liquid Crystals

ISSN: 1542-1406 (Print) 1563-5287 (Online) Journal homepage: http://www.tandfonline.com/loi/gmcl20

Liquid Crystal Properties and Self Alignment of Silver (Ag) Nanowires as a Function of Flow

Colin D. Preston, Lianbing Hu & L.J. Martínez-Miranda

To cite this article: Colin D. Preston, Lianbing Hu & L.J. Martínez-Miranda (2015) Liquid Crystal Properties and Self Alignment of Silver (Ag) Nanowires as a Function of Flow, Molecular Crystals and Liquid Crystals, 610:1, 235-239, DOI: 10.1080/15421406.2015.1026751

To link to this article: http://dx.doi.org/10.1080/15421406.2015.1026751

Published online: 06 Jul 2015.

Mol. Cryst. Liq. Cryst., Vol. 610: pp. 235–239, 2015

ISSN: 1542-1406 print/1563-5287 online
DOI: 10.1080/15421406.2015.1026751

Taylor & Francis
Taylor & Francis Group

Liquid Crystal Properties and Self Alignment of Silver (Ag) Nanowires as a Function of Flow

COLIN D. PRESTON, LIANBING HU,
AND L.J. MARTÍNEZ-MIRANDA*

Department of Materials Science and Engineering, Energy Research Center, University of Maryland, College Park, MD, USA

We study the liquid crystal properties of nanowires (NW) of silver (Ag) as a function of flow of the solvent. We are interested in the structure intermediate between the liquid crystal phase and the isotropic phase, known as the heterogeneous phase, and how preferentially "ordered" this phase becomes with flow. This heterogeneous phase refers to that phase where the NW's are aligned in general along one direction, like a liquid crystal, but from NW to NW they vary in their angular orientation.

Keywords nanowires; lyotropic liquid crystalline; polarized microscopy; transparent electrodes

1. Introduction

Transparent electrodes and connections are of interest because of their increased use in liquid crystal displays, photovoltaics, solar cells and light-emitting diodes. The most used transparent conductive film is indium tin oxide (ITO), but the limited supply of indium makes the research on other transparent conductive materials critical [1–6]. In addition, the ITO is not ideal for flexible devices, since it is a ceramic and it is brittle, which makes the research on materials such as silver more attractive [2, 3, 6, 7]. Ag NW's have been used for this purpose because of their high conductivity, good mechanical properties and ease of preparation of the Ag NW for the different applications where it is used [8, 9]. Other metals have been considered, such as copper, and carbon nanotubes [2, 7, 10, 11]. The connections are supposed to be invisible to the eye in the applications mentioned. Thus we need the nanowires assembled in a structure that is smaller than 50 μm [8], since any patterns larger will be visible to the naked eye.

The goals of this work are to use the nanowires (NW) in the heterogeneous phase as transparent electrodes for photovoltaics and solar cell applications instead of ITO; and to choose the arrangement where a directional current is obtained and where it will be maximum, while keeping the film's transparency.

*Address correspondence to L. J. Martínez-Miranda, Department of Materials Science and Engineering, University of Maryland, College Park, MD 20742, USA. E-mail: ljmm@umd.edu

Color versions of one or more of the figures in the article can be found online at www.tandfonline.com/gmcl.

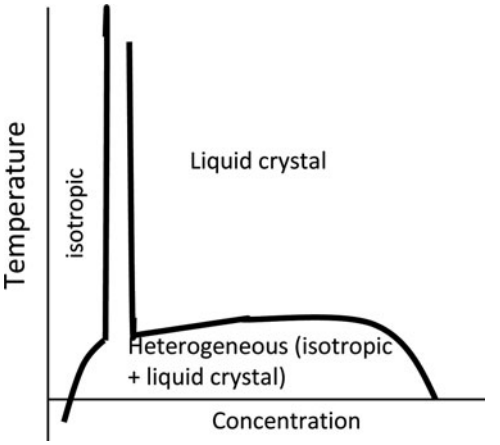

Figure 1. Phase diagram of temperature as a function of concentration, based on Refs. [12,13].

NW's form a lyotropic liquid crystal depending on the concentration of the solvent that serves as host [see, for example, 12]. The phase diagram for Ag NW's is believed to be similar to that shown in Figure 1 for rigid-rod polymers [12, 13]. The heterogeneous phase exhibits properties between the isotropic and the liquid crystalline phase. It can be influenced by flow [14 – 20].

The phase diagram under flow (flow vs concentration) is very similar to that in Figure 1. At present the specific shape of the phase diagram is under research. The desired heterogeneous phase is just underneath the liquid crystal phase (shown in the red cut line). This proximity ensures that the NW's are still overlapping, able to conduct the current and keeping NW grouping is tight.

2. Experimental

The flow can be varied using different techniques, such as tilting the substrate at different angles [12], or varying the velocity imposed when the sample is placed on the substrate with a pipette. The flow is varied by using gratings in this work. The gratings add another term to the speed of the NW's. The gratings contribute an open channel shear flow in addition to the Couette flow on the surface of the substrate seen in Equation 1 and in Figure 2.

$$v = \sqrt{\left(Av_{\text{open channel}}\right)^2 + \left(Bv_{\text{Couette}}\right)^2}, \text{A, B constants} \tag{1}$$

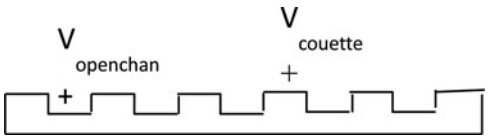

Figure 2. The contributions to the open channel shear flow and the coquette flow created by the grating.

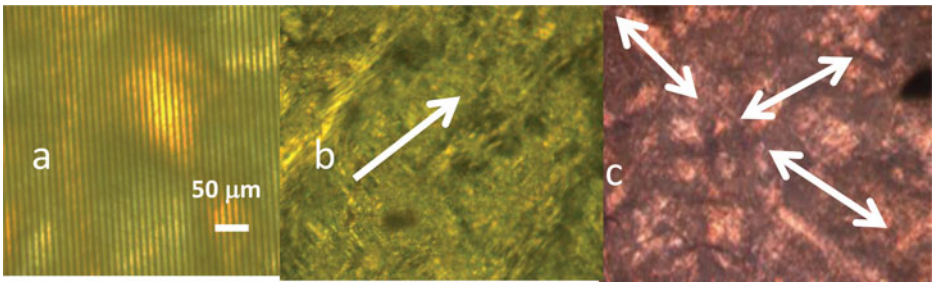

Figure 3. Deposition of a 10mg/ml mixture of Ag NW in ethanol in a 0.5 μm deep grated surface, just after deposition (a), and when the alcohol is almost evaporated (b), and a non-treated surface (c). The arrows in b and c designate the direction of the flow.

We have tested gratings of 0.5, 0.25 μm in depth and compared them with the case where there are no gratings on the substrate. Initially, we used a 10 mg/ml concentration of Ag NW. We analyze the samples using polarizing microscopy. The sample is filmed while the alcohol evaporates. This allows us to measure the shear flow. The final arrangement of the NW can be measured with a two point probe in order to measure the current.

3. Results and Discussion

The gratings impose a direction to the flow of the mixture as illustrated with the arrows depicted in Figure 3, which was taken with polarized microscopy. Figure 3 (a) and (b) show the NW's on a 0.5 μm grating just as the NW's are deposited n Figure 3 (a), and as the alcohol evaporates in Figure 3 (b). The arrow shows the direction of flow in Figure 3 (b). Figure 3 (c) shows the evaporation on a plain glass slide. The arrows show that the flow does not have a particular direction.

Figure 4 shows the orientation and relative size of the grouping of the resulting heterogeneous phase depending on the grating depth, just as the alcohol dries. The bright portions designate the NW's. Figure 4(a) shows the 0.5 μm deep grating; Figure 4(b) shows the 0.25 μm grating and Figure 4(c) shows the plain glass. The NW's are tighter and are oriented at almost 90° with respect to the gratings in Figure 4(a) as compared to Figure (b) and (c). An independent study using scanning electron microscopy (SEM). SEM

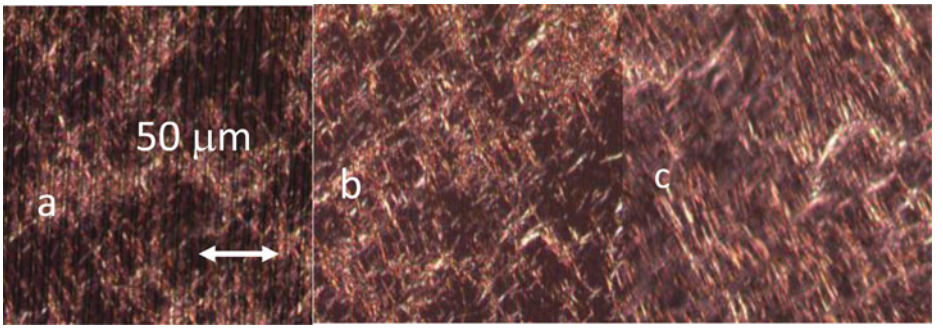

Figure 4. The structure of the NW's as the alcohol evaporates: a. the 0.5μm deep grating; b. the 0.2μm deep grating and c. no grating at all.

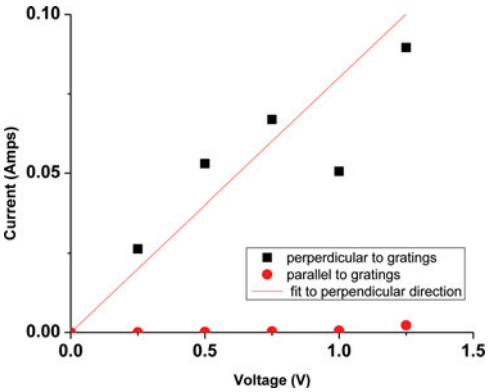

Figure 5. I-V curve for the 0.5 μm deep grating, in the direction perpendicular to the gratings (black) and parallel to the gratings (red). The curves give a resistance of 12.5 Ω for the perpendicular direction and larger than 2000 Ω for the parallel direction.

shows that the heterogeneously aligned NWs are at or close to 90° with respect to the gratings.

Figure 5 shows the IV curve taken on the 0.5μm deep grating. The IV curve in the direction perpendicular, designated by black, and parallel, designated by red, to the gratings measured with a two point probe shows that there is a directional current. The resistance shown is that for the heterogeneous bundles and is measured across the length of the set of NW's.

4. Conclusions

We have investigated the effect of the flow on the ordering of and the resulting phase of samples consisting of NW's of Ag. We have used gratings of different depths to vary the flow and to align the NW's along one direction. Our preliminary results show that one can obtain an ordered distribution of the heterogeneous phase and a directional current if we change the depth of the grating.

References

[1] Rui Zhu, Choong-Heui Chung, Kitty C. Cha, Wenbing Yang, Yue Bing Zheng, Huanping Zhou, Tze-Bin Song, Chun-Chao Chen, Paul S. Weiss, Gang Li, & Yang Yang, *ACS Nano*, *5*, 9877–9882 (2011).
[2] S. H. Lee, C. C. Teng, C. C. M. Ma, I. Wang, *Journal of Colloid and Interface Science*, *364*, 1–9 (2011).
[3] R. Zhu, C. H. Chung, K. C. Cha, W. B. Yang, Y. B. Zheng, H. P. Zhou, T. B. Song, C. C. Chen, P. S. Weiss, G. Li, Y. Yang, *ACS Nano*, *5*, 9877–9882 (2011).
[4] H. Wu, L. Hu, M. W. Rowell, D. S. Kong, J. J. Cha, J. R. McDonough, J. Zhou, Y. A. Yang, M. D. McGehee, Y. Cui, *Nano Letters*, *10*, 4242–4248 (2010).
[5] L. Hu, H. S. Kim, J. Y. Lee, P. Peumans, Y. Cui, *ACS Nano*, *4*, 2955–2963 (2010).
[6] S. Kim, S-Y Kim, J. Kim, J. H. Kim, *Journal of Materials Chemistry C*, *2*, 5636–5643 (2014).
[7] A. R. Madaria, A. Kumar, F. N. Ishikawa, C. W. Zhou, *Nano Research*, *3*, 564–573 (2010).
[8] J. S. Park, M. Rezaei, W. S. Kim, *Advanced Engineering Materials*, *16*, 905–908 (2014).
[9] T. Rai, P. Dantes, B. Bahreyni, W. S. Kim, *IEEE Electron Device Letters*, *34*, 544–546 (2013).

[10] M. Zhang, S. L. Fang, A. A. Zakhidov, S. B. Lee, A. E. Aliev, C. D. Williams, K. R. Atkinson, R. H. Baughman, *Science*, *309*, 1215–1219 (2005).
[11] E. M. Doherty, S. De, P. E. Lyons, A. Shmeliov, P. N. Nirmalraj, V. Scardaci, J. Joimel, W. J. Blau, J. J. Boland, J. N. Coleman, *Carbon*, *47*, 2466–2473 (2009).
[12] M. Bravo-Sanchez, T. J. Simmons, M. A. Vidal, *Carbon 48*, 3531 (2010).
[13] P. J. Flory, *Proc R Soc Lond Ser A – Math Phys*, *234*, 73–89 (1956)
[14] Jun-ichi Fukuda, Holger Stark, and Hiroshi Yokoyama, *Phys. Rev. E 72*, 021701 (2005).
[15] Sandeep D. Kulkarni and Jeffrey F. Morris, *Rheol. 53*, 417 (2009).
[16] Hernán E. Romeo, Cristina E. Hoppe, M. Arturo, López-Quintela, Roberto J. J. Williams, Yanina Minaberry & Matías Jobbágyc, *J. Mater. Chem.*, *22*, 9195 (2012).
[17] Christopher Chan, Gregory Crawford, Yuming Gao, Robert Hurt, Kengqing Jian, Hao Li, Brian Sheldon, Matthew Sousa, Nancy Yang, *Carbon 43* 2431–2440 (2005).
[18] Zhen Xu & Chao Gao, *ACS Nano*, *5*, 2908–2915, (2011).
[19] L. J. Martínez-Miranda, O. C. Wilson, Jr., Alicia Rose Douglas, *Mol. Cryst. Liq. Cryst.*, *409*, 91 (2004).