Supporting Information

Electrical and Network Properties of Flexible Silver-Nanowire Composite Electrodes under Mechanical Strain

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SI 1. Analysis of Light Microscopy Images using the Fiber Image Network Evaluation (FINE) Algorithm

SI 1.1. Image processing

Prior to the quantitative evaluation of the orientation and morphology of the nanowire networks, light microscopy images were preprocessed using the open-source platform ImageJ (Fiji).[1] The 2448 x 2048 pixels source images were converted to greyscale and cropped to quadratic shape. The background signal was removed using the function Subtract Background with a rolling ball radius of 50 pixels to account for its local variations. To enhance the contrast of the nanowires in each image equally a grey value saturation of 2 % of the pixels was enforced using the function Enhance Contrast.

SI 1.2. Analysis

Preprocessed images were then evaluated by the Fiber Image Tissue Evaluation algorithm (FINE algorithm).[2] The FINE algorithm uses a sigmoid model, which contains the amplitudes, mean orientations, and dispersions of N fiber families. The model is fitted iteratively to the cumulative orientation distribution (COD), which is obtained by a Fourier domain-based method from the grey scale images.[3] The number of determined fiber families increases with each iteration of the FINE algorithm until termination is enforced by a criterion based on the uncertainty of the COD. An identified fiber family is considered as isotropic if its dispersion parameter is smaller than 0.05.[2] The production of the composites resulted in isotropic nanowire networks. Nevertheless, it is conceivable that the wires in the polymer matrix align when the composite is stretched. Thus, the orientation of the nanowires was investigated to check for the existence of an anisotropic fiber family. Figure SI1(a) shows the amplitudes obtained by the FINE algorithm for three samples with nanowire concentrations of 40 µg $\text{cm}^{-2,}$ 80 µg cm^{-2} and 120 µg cm^{-2}. It can clearly be seen that the algorithm converged for only one isotropic fiber family with an amplitude of 1. Furthermore, all determined dispersion parameters are smaller than 0.05, strongly indicating isotropic fiber distribution within all samples over all stretching steps (see Figure SI1(b)). Figure SI1(c) shows the orientation indices for all three samples.

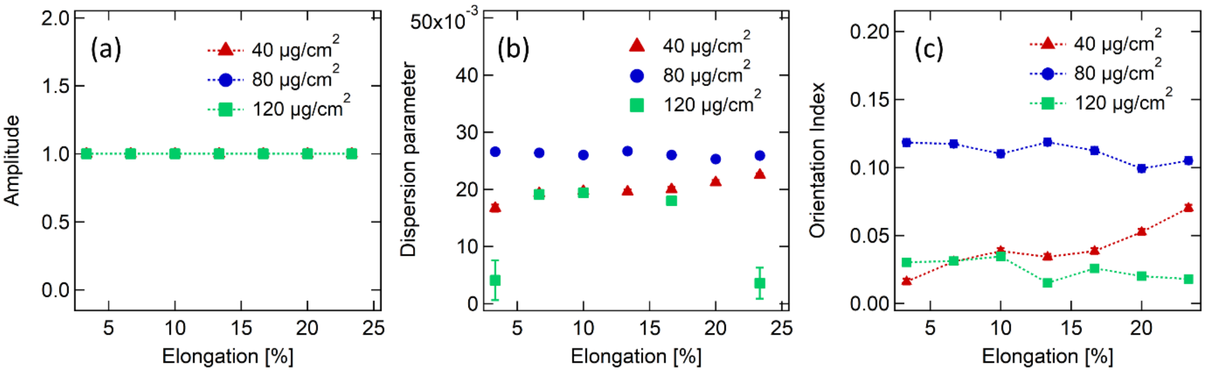

Fig. SI1: (a) Amplitudes of all fiber families determined by the FINE algorithm for micrographs of three silver nanowire samples with different concentrations. For all samples one isotropic fiber family with an amplitude of 1 was found. The amplitude of any additional possible family stays zero. (b) Dispersion parameters for the isotropic fiber family found for the samples shown in (a). (c) Orientation index found for the same samples.

SI 2. Analysis of Monte-Carlo Simulated Nanowire Networks

In order to investigate the impact of alignment of the nanowires during stretching, the alignment was simulated and the resulting network was analyzed.

An isotropic nanowire network was created (see Figure SI2(a)) using a typical Monte-Carlo-method as described in the main text. For the stretched network, the x-component d*x* of the vector that describes a wire was adapted in accordance with the respective elongation to $d\tilde{x} = dx * (1 + E_{[\%]}/100)$. The orientation angle of the wire ϑ_i was then adapted by $\cos(\theta_i) = d\tilde{x}/L_i$, where L_i is the fixed length of a wire *i*. Furthermore, the positions of the wires were changed in accordance to the elongation. The resulting network is shown in Figure SI2(b)-(d) for elongations of 3.3 %, 13.3 % and 23 %. The images were analyzed by the FINE algorithm.[2] In contrast to the results gathered from the experiments, two families of fibers were found, one isotropic and one anisotropic. The amplitudes of both families are shown in Figure SI2(e). The anisotropic family arises during stretching and shows a mean orientation in stretching direction. The corresponding orientation index is shown in Figure SI2(f). At an elongation of 23 %, a strongly anisotropic sample was found, which led to an increase in the orientation index to 0.5. Compared to our findings in the light microscopic images of the Ag-NW composite samples, this artificial orientation found by simulation is much higher than the experimentally observed morphological changes.

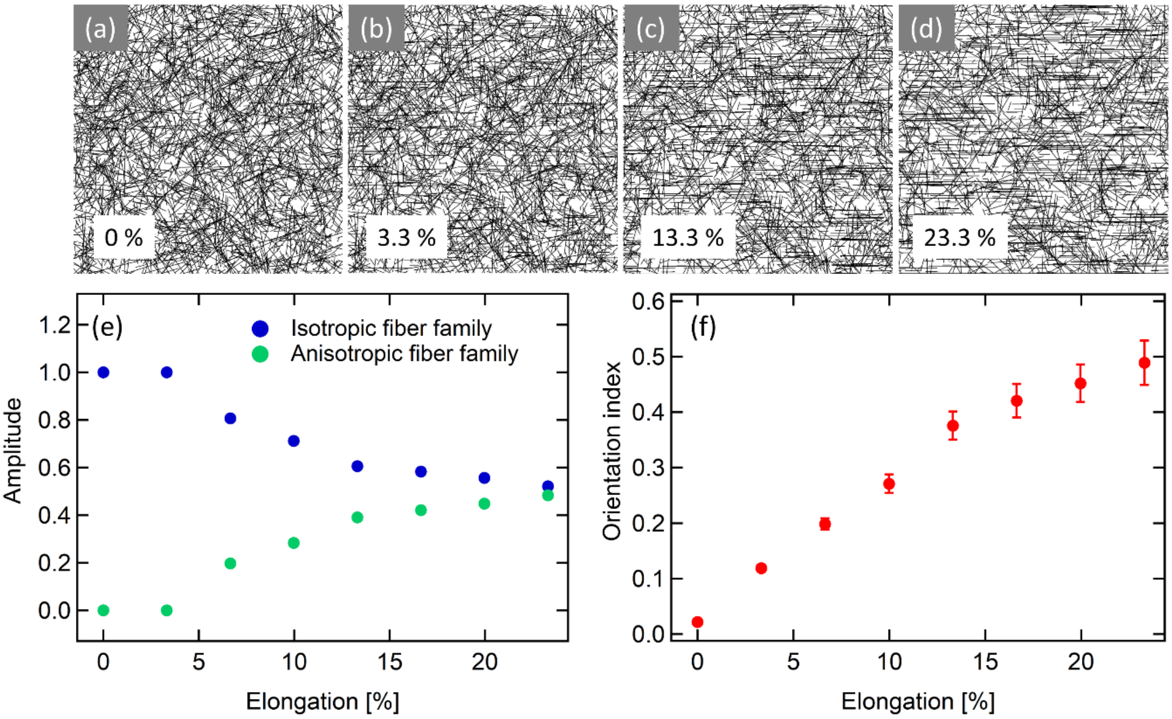

Fig. SI2: (a) Monte-Carlo simulation of a nanowire network with a size of 400 µm x 400 µm and an effective nanowire concentration of 20 µg cm^{-2}. The nanowire positions and orientations were determined randomly. (b)-(d) The same network shown in (a) for the exemplary stretching steps. For stretching, the positions as well as the orientation of the wires was changes corresponding to the elongation of the sample. (e) Amplitudes of the two fiber families found by the FINE algorithm. (f) Orientation index for the simulated nanowire networks.

SI 3. Morphological Observations

Figure SI3 (a) and (b) show exemplary micrographs of unstretched samples before stretching (Fig. SI3(a)) and after stretching the sample to 23 % elongation and relaxation of the sample back to 0 % elongation (Fig. SI3(b)). The network morphology as well as the electrical properties of the sample recovers qualitatively. Some small local changes can be observed and are marked by circles: The green circle depicts a wire, which is straight before stretching and curved after stretching. The yellow and red circles highlight small rearrangements of wires after stretching and relaxation and the violet circle shows a wire, which is broken after stretching. However, these changes are small and rare and in general the nanowires are stable under stretching. Due to the fact that the nanowires are not welded the network is flexible und changes upon stretching are reversible.

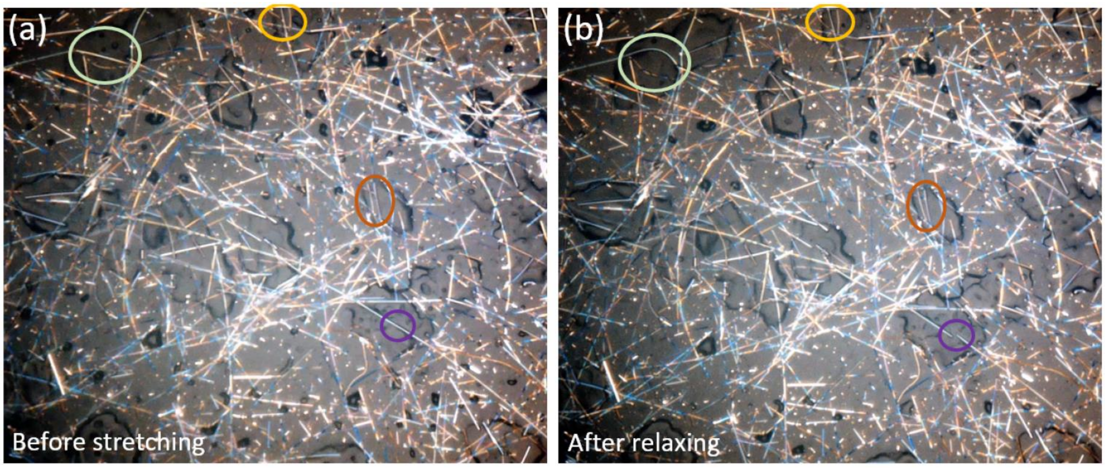

Fig. SI3: (a) Micrograph of a Ag-NW polymer composite with a concentration of 100 µg cm^{-2} before stretching. (b) Micrograph of the same sample after stretching to 23 % elongation and relaxation to 0 %. The circles highlight rare changes in the network. Green: A straight nanowire is curved after stretching and relaxation. Yellow and red: Nanowires are slightly rearranged. Violet: A nanowire is broken.

Literature

1 J. Schindelin, I. Arganda-Carreras, E. Frise, V. Kaynig, M. Longair, T. Pietzsch, S. Preibisch, C. Rueden, S. Saalfeld, B. Schmid, J.-Y. Tinevez, D. J. White, V. Hartenstein, K. Eliceiri, P. Tomancak and A. Cardona, *Nat. Methods*, 2012, **9**, 676–682.
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