Effect of Reactive Dyeing on Fabrics Modification with Silver Nanowires (AgNWs)

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ABSTRACT: This paper presents the characterization of cotton and wool fabrics modified by silver nanowires (AgNWs). The effect of reactive dyeing of wool and cotton fabrics on their modification with AgNWs was analyzed. Both fabrics were dyed using reactive dyes (yellow, red, blue) at four color intensities (0.5, 1, 2, and 5%). Dyed fabrics were characterized by the determined Kubelka–Munk’s coefficient (K/S) ratio and vibrational spectra (Fourier transform infrared (FTIR) and Raman). Analysis of the amount of AgNWs applied on cotton and wool fabrics indicates that the presence of dye affects the surface modification with AgNWs depending on the type of fibers. While for cotton no significant differences were noted in relation to the color intensity, in the case of wool, the higher the dye contents, the more nanowires were deposited on the surface. Surface-enhanced Raman spectroscopy (SERS) effect accompanying AgNW modification was also observed on wool, similar to the previous study on cotton.

1. INTRODUCTION

The development of research on the fibrous structural modification using nanoparticles is the result of the growing market demand for functional textile materials. Functionalization with the use of metal nanoparticles and metal oxides plays a special role, giving textile products characteristics such as bioactivity, UV protection, catalytic, or conductive properties. Silver nanowires (AgNWs) attracted considerable attention in applications such as biological/electrochemical sensors due to their unique properties. Application of AgNWs for the functionalization of cotton and viscose fibers allowed us to obtain bifunctional textiles with conductive and antibacterial properties. AgNWs were applied to modify nylon, cotton, polyester, and cupro fabrics to obtain electrically conductive materials. Successful attempts of silver nanowire modification were also made on wool. Knitted wool coated with silver nanowires was applied for wearable electronics for several applications, e.g., electrodes, flexible capacitor sensors for controlling light-emitting diodes (LEDs), capacitive pressure sensors for detecting different standard weights, and sensors for detecting body motions. The modifications mentioned above were carried out for undyed textiles. There are also studies showing that nanosilver not only hinders dyeing processes but also can be used as a coloring agent. The treatment of wool with silver nanoparticles can improve its properties, i.e., better tensile strength and drying time, enhance the color strength of dyed wool fibers (direct dye and acid dye), and also improve the fastness toward light and washing. Pretreatment of wool improves the resistance to microbial attack.

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however, the fluorescence appearing after light excitation sometimes makes the analysis of Raman very difficult and often impossible to obtain a Raman spectrum. This is particularly evident in the case of natural polymers, where the intensity of fluorescence can be up to $10^4$ times higher than that of Raman scattering. The presence of dyes in the fiber can also be a factor impeding its analysis by this technique. Modification with silver nanoparticles in addition to functionalizing the fibers also changes the possibilities of their analysis because silver nanoparticles can limit fluorescence and the presence of noble metals on the fiber surface can enhance the Raman signal, which was described in our previous work for cotton. Surface-enhanced Raman spectroscopy (SERS) based on Raman signal enhancement is a very valuable tool that can provide unique characterization data concerning textile analysis including quantifying nanosilver and characterizing nanoparticle distribution on the modified textile surface.

The aim of this work is to analyze the effect of the reactive dyeing of wool and cotton fabrics on their modifications with AgNWs. A previous study on the dyed and undyed cotton fabrics modified with AgNWs has proven that the fabric dyed with a reactive dye can be further modified with AgNWs. Current studies concern fabrics made of two different types of natural fibers dyed with the same reactive dyes and then modified with AgNWs. The study of how the presence of the dye affects the effectiveness of the functionalization of AgNW fabrics will be important for further work on making the textile materials bioactive or electrically conductive.

2. MATERIALS AND METHODS

2.1. Materials. WO: 100% wool plain-woven fabric (115 g/m², pick and end densities: warp 16 and weft 16).

CO: 100% cotton plain-woven fabric (108 g/m², pick and end densities: warp 43 and weft 32).

The samples of fabrics were dyed using three reactive azo dyes with sulfonate groups (Archroma, Germany): Drimaren Yellow CL-2R (CI RY 176), Drimaren Red CL-SB (CI RR 241), and Drimaren Blue HF-RL (CI RBL 221). Drimaren Yellow, RY; Drimaren Red, RR; Drimaren Blue, RB; cotton fabric, CO; and wool fabric, WO.

Both fabrics were dyed in an Ahiba Nuance Laboratory dyeing machine (bath ratio: 1:100).

Wool dyeing: the ready-to-dye samples of wool fabric (2 g) were used. The dye baths contained a reactive dye (0.5, 1, 2, and 5% on weight of fibers). To ensure the correct reaction environment, Na₂CO₃ (1 g/L) and CH₃COOH amounts were added to obtain a pH = 7 to each bath separately. The dyeing process was conducted for 76 min; it was started at a temperature of 22 °C and heated until it reached 98 °C at a rate of 1 °C/min. Dyeing was continued at this temperature for 60 min, and next, the bath was cooled to 70 °C. The dyed fabrics were rinsed three times with cold (18 °C) water and dried at ambient temperature.

Cotton dyeing: the ready-to-dye samples of cotton fabric (2 g) were used. The dye baths contained a reactive dye (0.5, 1, 2, and 5% on weight of fibers), and Na₂CO₃ amount was added to reach a pH = 8 to each bath. The process was started at a temperature of 22 °C, and then the temperature was increased to 60 °C at a rate of 1 °C/min. Dyeing was continued at this temperature for 60 min, and next, the bath was cooled to 40 °C. The dyed fabrics were rinsed three times with warm (50 °C) and cold (18 °C) water and dried at ambient temperature.

2.1.1. Silver Nanowires (AgNWs). A AgNW colloid concentration of 0.5% and the length of nanowires of about 10 μm were used for the modification of undyed and dyed fabric samples. The nanowires were applied to the surface of the fabrics by the dipping and drying method (dipping for 1 min and drying at 23 °C for 30 min). Fabrics for modifications were cut into pieces (1 cm × 2 cm) and weighed (three repeats) using an ONYX OX220 Balance (FaWaG, Poland) with a resolution of 0.0001 g before and after AgNW application.

2.2. Methods. 2.2.1. K/S Determination. K/S values were determined on the basis of the results of tests performed on a CM 2600d (Konica Minolta) reflection spectrometer in the following conditions: color system CIE L*a*b*, light D65, observation angle 10°.

2.2.2. FTIR ATR Spectroscopy. IR spectra were obtained on a VERTEX 70 FTIR spectrometer (Bruker, Germany) with the ATR Golden Gate Diamond Accessory (Specac, U.K.). Absorption spectra at a resolution of one data point per 2 cm⁻¹ were obtained in the region between 400 and 4000 cm⁻¹. Typically, 64 scans were collected, Fourier-transformed, and averaged for each measurement. The recording of spectra was carried out by means of Bruker OPUS 6.5 software (version 6.5).

All spectral processing were done with the use of Microcal Origin 8.0 software.

2.2.3. Raman Spectroscopy. Raman-dispersive spectrometer: a Renishaw InVia Reflex with a Leica microscope (Renishaw, GB) was used in the study. An excitation source of $\lambda = 785$ nm, 300 mW, was applied with a spectral resolution of 1 cm⁻¹. The spectra of dyed and undyed samples were accumulated within a 10 s integration time. The laser power was dependent on the sample and varied from 1 to 10% of the power.

The analysis by the Raman technique was carried out in a closed microscope chamber of the spectroscopy, with samples being placed on the microscopic plate. Samples were positioned
at the focus of laser light by means of a microscope (magnification 20×) with a charge-coupled device (CCD) camera. The recording of spectra was carried out using Renishaw WIRE 5.2 software (version 5.2). All spectral processing were done with the use of Microcal Origin 8.0 software.

Table 1. K/S Values for Wool and Cotton Fabrics Dyed with Reactive Dyes

| color intensity (%) | cotton K/S | wool K/S | λ (nm) |
|-------------------|-----------|----------|--------|
| yellow 0.5        | 0.20      | 4.1      | 430    |
| 1                 | 0.46      | 8.4      |        |
| 2                 | 1.10      | 10.8     |        |
| 5                 | 2.35      | 23.0     |        |
| red 0.5           | 0.05      | 2.2      | 555    |
| 1                 | 0.12      | 3.8      |        |
| 2                 | 0.38      | 6.0      |        |
| 5                 | 1.15      | 12.8     |        |
| blue 0.5          | 0.08      | 3.5      | 627    |
| 1                 | 0.25      | 6.8      |        |
| 2                 | 0.70      | 15.2     |        |
| 5                 | 1.70      | 26.5     |        |

Table 2. IR Characteristic Bands of Wool and Reactive Dyes

| bands (cm⁻¹) | description | wool fabric | dyes |
|--------------|-------------|-------------|------|
| 668          | CH₂, CONH bending | RY, RR, RB | RY, RR, RB |
| 734          | C─N, C─O, stretching | RY, RR, RB | RY, RR, RB |
| 967          | N─H bending, CH wagging (amide II) | RY, RR, RB | RY, RR, RB |
| 932          | CH₂, CONH bending | RY, RR, RB | RY, RR, RB |
| 1074         | C─N, C─O, stretching | RY, RR, RB | RY, RR, RB |
| 1235         | CNH₂ twisting, amide III | RY, RR, RB | RY, RR, RB |
| 1393         | CH₃ stretching | RY, RR, RB | RY, RR, RB |
| 1515         | N─H bending, CH wagging (amide II) | RY, RR, RB | RY, RR, RB |
| 1630         | C─O (amide I) | RY, RR, RB | RY, RR, RB |
| 2930         | CH stretching | RY, RR, RB | RY, RR, RB |
| 3278         | NH stretching | RY, RR, RB | RY, RR, RB |

Figure 2. Ratio of K/S coefficients calculated on the basis of the diffuse reflectance spectra and Kubelka–Munk equation vs dye concentration for yellow-, red-, and blue-dyed wool fabrics.

Figure 3. IR spectra of wool before and after dyeing: (a) RY, (b) RR, and (c) RB.

2.2.4. SEM/EDS Measurement. Scanning electron microscopy/energy-dispersive spectroscopy (SEM/EDS) analysis: microscopic measurements of the surface topography of the materials were carried out on a VEGA3 TESCAN (TESCAN ORSAY HOLDING, Brno, Czech Republic) scanning electron microscope equipped with an electron optics system, enabling observation of the surfaces of the materials at a 4–1 000 000-times magnification across an energy range of the incident electron beam from 0.2 to 30 keV with a maximum resolution of...
3 nm in the secondary electron emission mode and 3.5 nm in the backscattered electron mode. Scanning electron microscopic (SEM) images of the surface topography and cross sections were taken using a high-vacuum mode (20 keV probe energy). The surface of each preparation was sprayed with a conductive substance (gold) using a vacuum sputter (Quorum Technologies Ltd., Lewes, U.K.). For surface topography studies, magnifications of 120×, 5000×, and 10 000× were used. Elemental analysis was performed using an EDS INCA energy X-ray energy dispersion spectrometer from Oxford Instruments (Abingdon, U.K.). Elemental analysis for both CO and WO was carried out under 120× magnification on an area of a square with a side of 1.81 mm at a measured area of 3.2761 mm$^2$. Three tests were carried out each time, and the average values of these measurements were presented.

### 3. RESULTS AND DISCUSSION

#### 3.1. Characterization of Dyed Fabrics

**3.1.1. K/S Determination.** The ratio $K/S$ of absorption ($K$) and scattering ($S$) coefficients was calculated using the Kubelka–Munk equation for wool fabrics. Reflectance values were calculated at the maximum of absorption bands ($\lambda = 430, 555,$ and 627 nm for yellow-, red-, and blue-dyed samples, respectively). The ratio $K/S$ values for wool are higher than those for cotton of 20, 43.5, and 44 times respectively (Table 1). For comparative duties, they are also presented in Table 1.

The $K/S$ values for wool are much higher than those obtained for cotton. The differences are greater in the case of lower color intensity. For samples at a 0.5% color intensity, $K/S$ values for wool are higher than those for cotton of 20, 43.5, and 44 times for yellow, red, and blue, respectively. The differences in the case of a 5% color intensity for yellow, red, and blue are 9.8, 11.1, and 15.6 times, respectively. These differences indicate that the reactive dyes mentioned are absorbed on the wool in a greater amount than on cotton.

The $K/S$ ratio should be approximately proportional to the dye concentration, and this relationship is fulfilled for wool, as presented in Figure 2, as it was also previously noted for cotton.

Despite the much higher $K/S$ values for wool, there are no observed deviations from the relationship with increasing dye concentration (Figure 2), although such deviations were reported earlier in the literature on the example of dyeing cotton knitwear with reactive dyes.

#### 3.1.2. Vibrational Spectroscopy

Vibrational spectroscopic methods were applied to characterize reactive dyes, dyed fabrics, and an undyed wool fabric as a reference. In the IR spectra of wool before and after dyeing (Figure 3), only bands characteristic for wool are observed; even for the sample with the highest color intensity, no bands of reactive dye appeared. However, the changes in the vibration intensity were observed on the IR spectra of undyed and dyed wool. In the case of wool dyed with RR, an increase in the intensity of 1515, 1630, and 3278 cm$^{-1}$ bands was noted for the sample of a 5% color intensity and a slight decrease in the intensity of amide bands at 1515 and 1630 cm$^{-1}$ for the sample of a 0.5% color intensity. In the spectra of wool dyed with RR and RB, an increase in the intensity of the

### Table 3. Raman Fingerprint Bands of Wool and Selected Reactive Dyes

| bands (cm$^{-1}$) | description | wool fabric | dyes |
|-------------------|-------------|-------------|------|
| 510               | SS stretching | RY          | RR   |
| 752               | CCC, stretching |              |      |
| 855               | CH$_2$, HCS bending |              |      |
| 899               | CCCO~ stretching |              |      |
| 936               | CH$_2$, HCS bending |              |      |
| 1005             | NCH bending |              |      |
| 1312, 1457        | CH$_2$ bending |              |      |
| 1514, 1631        | NH bending |              |      |
| 1660             | C=O, COO~ stretching |              |      |
| 2931, 2959        | CH stretching |              |      |
| 3276             | NH stretching |              |      |

results for wool are presented in Table 1. The values of the $K/S$ ratio for cotton fabrics were given in our earlier paper; however, for comparative duties, they are also presented in Table 1.
bands at 1515, 1630, and 3278 cm\(^{-1}\) for each color intensity was recorded. This is due to the change in the dipole moment of amide and NH stretching bond interactions, which is the result of interactions between wool and dye particles. When the dyed cotton was analyzed in our previous research,\(^{19}\) in IR spectra of each cotton sample, only bands characteristic for cotton were observed, without changes in their peak intensities.

The reason for the observed spectral changes of both fabrics dyed with the same dye is the different dye-binding mechanisms of wool and cotton.\(^{27}\) The IR spectra of the dyed wool confirm the reaction of dye with the wool amide groups, while in cotton dyeing, the OH group of cellulose reacts with the chloride ion of the dye molecule. Spectral changes may also be due to the fact that wool absorbs more dye than cotton, which is confirmed by the quantitative differences in the relative color strength (K/S) for both fabrics (Table 2).

Raman spectra of dyed wool fabrics (Figure 4) indicate that all three dyes could be identified at a 0.5% color intensity. In the case of cotton, the same dyes at a color intensity of 0.5% were already detected only for fibers after modification with AgNWs, thanks to the SERS effect.\(^{19}\) The obtained Raman results correspond with the determined K/S values and IR spectra, indicating quantitative differences in the dye uptake by wool and cotton. These differences are the result of both physical and chemical interactions. The dye absorption can also be related to the structure of the fiber. It was reported earlier that wool fiber has a porous core and its internal layers can be partially accessible to the dye molecule, as reported in the case of gas absorption.\(^{30}\) The chemistry of the dyeing process indicates that the other functional groups of the reactive dye molecules are involved in the dyeing of cotton and others in wool dyeing. In cotton dyeing, the Cl ion from the dye molecule is arranged, while in wool dyeing, the SO\(_3\)\(^{-}\) groups bind to wool-reactive sites,\(^{31}\) mainly NH groups. Thus, more active places for dye and fiber binding are found in the case of wool. The characteristic Raman vibrations of wool and reactive dyes are listed in Table 3. The most important observed feature in the wool spectrum is the presence of a band at 510 cm\(^{-1}\), characteristic of the S\(\equiv\)O vibration and occurs at 1660 cm\(^{-1}\). The amide I band corresponds to the C\(\equiv\)O vibration and occurs at 1600 cm\(^{-1}\).

Moreover, some significant details in dyed wool spectra are noted. It has been observed that there is an increase in the spectrum baseline of wool in the range between 200 and 600 cm\(^{-1}\), as the effect of fluorescence that is typical for natural fibers.\(^{19}\) The characteristic bands for the RY and RR dyes are identified in the spectrum of the dyed fabric as distinct but not very intense peaks (Figure 4a,b) and are attributed to aromatic ring vibrations (1418 cm\(^{-1}\), RR; 1615 cm\(^{-1}\), RY). In the case of the RR dye, the CN stretch at 1142 cm\(^{-1}\) can be distinguished. In the case of wool dyed with RB (Figure 3c), the dye-specific bands characteristic of the SO\(_2\) group are dominant in the spectrum, and the wool bands are of weak intensity. This feature can be a result of the interaction with the laser excitation light (785 nm) that can excite the blue-dyed

| color/dye intensity | mass of applied AgNWs (g) | AgNW content in the fabric sample (%) | color/dye intensity | mass of applied AgNWs (g) | AgNW content in the fabric sample (%) |
|---------------------|---------------------------|--------------------------------------|---------------------|---------------------------|--------------------------------------|
| CO/0%               | 0.0046 ± 0.0011           | 3.3367 ± 0.0003                      | WO/0%               | 0.0071 ± 0.0009           | 3.7767 ± 0.0026                      |
| CO/RB 0.5%          | 0.0080 ± 0.0012           | 5.7333 ± 0.0047                      | WO/RB 0.5%          | 0.0149 ± 0.0077           | 7.8133 ± 0.0036                      |
| CO/RR 0.5%          | 0.0077 ± 0.0006           | 5.3333 ± 0.0009                      | WO/RR 0.5%          | 0.0072 ± 0.0017           | 4.7500 ± 0.0023                      |
| CO/RR 5%            | 0.0080 ± 0.0012           | 6.1667 ± 0.0005                      | WO/0%               | 0.0136 ± 0.0034           | 6.6900 ± 0.0009                      |
| CO/RY 0.5%          | 0.0043 ± 0.0009           | 3.2267 ± 0.0015                      | WO/RY 0.5%          | 0.0218 ± 0.0036           | 9.0800 ± 0.0013                      |
| CO/RY 5%            | 0.0027 ± 0.0012           | 1.9367 ± 0.0011                      | WO/RB 5%            | 0.0036 ± 0.0012           | 2.400 ± 0.0053                       |
| CO/RB 5%            | 0.0047 ± 0.0007           | 3.8933 ± 0.0039                      | WO/RR 5%            | 0.0117 ± 0.0004           | 6.0733 ± 0.0065                      |

Table 4. AgNW Contents on CO and WO Fabrics

| color/dye intensity | Ag (%) average | color/dye intensity | Ag (%) average |
|---------------------|---------------|---------------------|---------------|
| CO/0%               | 1.51 ± 0.09   | WO/0%               | 2.13 ± 0.20   |
| CO/RB 0.5%          | 3.63 ± 0.18   | WO/RB 0.5%          | 3.43 ± 0.33   |
| CO/RR 0.5%          | 1.78 ± 0.09   | WO/RR 0.5%          | 4.42 ± 0.26   |
| CO/RR 5%            | 3.28 ± 0.36   | WO/RR 5%            | 4.86 ± 0.15   |
| CO/RY 0.5%          | 2.48 ± 0.27   | WO/RR 5%            | 7.69 ± 0.58   |
| CO/RY 5%            | 1.45 ± 0.15   | WO/RR 5%            | 1.89 ± 0.12   |
| CO/RB 5%            | 2.18 ± 0.15   | WO/RB 5%            | 3.49 ± 0.49   |

Table 5. EDS Results of Fabrics before and after AgNW Application
molecule, strengthening its Raman signal, as its visible absorption maximum is at 627 nm.\textsuperscript{19} Under the light excitation, a competing photochemical process could take place, but the dynamic methods should be involved to explore this mechanism (i.e., laser photolysis study).

### 3.2. Characterization of AgNW-Modified Fabrics

Table 4 presents the percentage results of AgNWs in the CO and WO fabrics dyed with 0.5 and 5% color intensities. The obtained results of mass measurements indicate that, in the case of wool, there is a dependence that the mass of the applied AgNWs increases with the increase of the dye concentration. In the case of cotton, it was also observed that the weight of silver nanowires deposited on the surface is higher in the case of dyed samples than in undyed cotton; however, the weight of AgNWs does not increase with the dye concentration (e.g., in the case of RR dye, the highest amount of AgNWs applied to dyeing is 0.5%). This difference is influenced by both the different morphological structures of cotton and wool fibers and a different mechanism of their reactive dyeing.

![SEM images of fabrics modified by AgNWs—undyed sample and samples dyed with reactive dyes of 0.5% and 5% color intensities: (a) fibers of cotton fabric, 5000× magnification, and (b) fibers of wool fabric, 5000× magnification.](image-url)
EDS results showed the same relationship concerning the amount of Ag detected on the modified fabric surface and are summarized in Table S. Figure 5 illustrates the results of AgNW modification by both mass weight measurement and EDS. In general, the amount of AgNWs absorbed on the dyed fabrics is higher than that for the undyed ones. Reactive blue is the exceptional case—for the samples of a 0.5% dye concentration, the amount of AgNWs is slightly less than that for the undyed fabric for both cotton and wool. These differences are very low but they confirm a different behavior of RB dye than that of Ry and RR, which was observed in Raman analysis. The obtained results indicate the possible favorable interactions between the reactive dye and the AgNW modifier. The effect of silver nanoparticles that can attach to the dye molecules and improve the color strength of wool was reported earlier,31 and similar relation between silver and reactive dye on wool and also on cotton can be assumed.

The SEM images presented in Figure 6 show the fabrics modified by silver nanowires. In the SEM images, AgNWs and poly(vinylpyrrolidone) (PVP) used for AgNW stabilization are observed.

The surface of the cotton fiber is a flat and twisted ribbon with a thick wall and small lumen (Figure 7a), whereas wool fibers have a unique surface structure of overlapping scales (Figure 7b). Hence, on the wool surface, the coating spreads over the scales and forms a thick polymer crust in some places and makes the polymer layer clearly visible on SEM images (Figure 6b).

While in the case of cotton (Figure 6a), the coating spreads more evenly on the surface and SEM images do not show polymer beads on the cotton surface. The presence of poly(vinylpyrrolidone) (PVP) bands was found in the Raman spectra of wool modified by AgNWs (Figure 8). The Raman technique also confirms the presence of Ag on the surface (Figure 8). The SERS effect caused by silver is also observed on wool, especially on the sample of a 0.5% dye concentration, owing to which the characteristic bands of PVP are observed at 364, 755, 853, 955, 1247, 1434, and 1768 cm\(^{-1}\), which could be the enhancement of the C=O bond of PVP from AgNW colloid used to the modification.35 The triple band with the maximum at 1533, 1586, and 1616 cm\(^{-1}\) can be assigned to the reactive red dye. The additional Raman bands at 453 and 674 cm\(^{-1}\) might be the SERS effect resulting from chemical enhancement.19,36 The PVP used to synthesize AgNWs10 and to stabilize the growth of AgNWs determines their size and longitudinal shape.24 The presence of the polymer coating around the wires, visible in SEM images and confirmed as PVP by the Raman spectrum, proves that the PVP is still present with nanowires. In the Raman spectra of the AgNW-modified wool, the presence of Ag on the surface is evidenced by the presence of a sharp band at 234 cm\(^{-1}\). This band is the effect of oxygen adsorption on the surface and it is assigned to the Ag—O coordination band.11,35 For unmodified wool, no differences were found in the intensity of the 234 cm\(^{-1}\) band regardless of the color intensity or type. The same results are observed for cotton. This is due to the fact that silver detection by Raman spectroscopy is only of a qualitative nature.

Between the reactive dye and PVP, there are physical interactions such as hydrogen-bonding or electrostatic interaction and PVP binds the reactive dye and the complexation of the reactive dye and PVP.17 In the previous work, the presence of PVP on the surface of the modified cotton was found.19 Both the K/S and FTIR results indicate a higher dye absorption by wool than by cotton. This regularity is confirmed when we analyze the SEM/EDS results, as the Ag content on the surface of the wool fabric is higher than that of the cotton fabric. Considering the ease of complexing PVP with a reactive dye, as well as the fact that silver ions also interact with the reactive dye,21 a conclusion can be drawn that the reactive dye is an important factor favoring fabric modification with AgNWs in the presence of PVP.

4. CONCLUSIONS

The aim of this work was to investigate the influence of the presence of reactive dyes on the wool and cotton fibers on
modification with AgNWs. Mass measurements of the modified cotton and wool, as well as EDS results, indicate that reactive dyeing is the factor favoring the modification by silver nanowires. The presence of PVP as a stabilizer of nanowires additionally affects the quantitative effect of modification, as PVP spontaneously complexes with reactive dyes.

The SERS effect accompanying the AgNW modification is observed on the wool fabric surface. FTIR analysis of wool before and after dyeing proved that, similarly to cotton, none of the analyzed reactive dyes could be detected when this method was applied. Anyway, intensity changes in the IR spectra of wool accompanying the reactive dye were noted. These changes are determined by different fiber structures and dye-binding mechanisms of wool and cotton. The complementarity of both vibrational spectroscopy methods can be a very good tool for the quick identification of fabrics, both dyed and undyed, and can provide information regarding intermolecular interactions in fiber dyeing.

Color strength measurements also indicate quantitative differences in the dye uptake by wool and cotton. This work confirms that the application of the silver nanowires on the fabric surface, beyond the functional aspects, can also give an additional value in Raman analysis due to SERS phenomena appearing on the fibrous surface modified with AgNWs.

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Notes

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