Measurement of Nanoscale Surface Roughness using Electronic Speckle Pattern Interferometer

P. P. Padghan[1], V. D. Pande[1], P. U. Ingle[3], S. S. Sen[2], A. K. Gade[3] and K. M. Alti[1,a]

[1]*Department of Physics, Sant Gadge Baba Amravati University, Amravati, Maharashtra, India*
[2]*Department of Chemical Technology, Sant Gadge Baba Amravati University, Amravati, Maharashtra, India*
[3]*Department of Biotechnology, Sant Gadge Baba Amravati University, Amravati, Maharashtra, India*
[a] Corresponding author: kamleshalti@sgbau.ac.in

Abstract. In this article, we have reported surface roughness of silver nano particle treated handmade paper sheets using electronic speckle pattern interferometer (ESPI). Paper sheets are specially designed for showing antimicrobial activities. Surface roughness values of nano particle treated paper sheets were compared with untreated paper sheets. Typical surface roughness was found to be in range of 100-200 nm.

INTRODUCTION

Silver nano particles are known for their antimicrobial activities [1,2]. Presence of silver nano particles in paper sheets opens up its potential application in water purification and food packaging [3,4]. Silver nano-particle impregnated paper exhibit different surface roughness than without it. To probe this further, we have used Electronic speckle pattern interferometer technique for evaluating surface roughness of some silver nano particle with impregnated and without impregnated paper sheets. Electronic speckle pattern interferometer (ESPI) is a non-destructive optical technique [5]. ESPI technique has wide applications. It is used for the measurement of surface deformation of samples [6,7], structure and shape monitoring [8]- [9], thermal stress analysis [10], thin films study [11] and roughness measurement [12]. Applications of this technique are growing day by day. In this paper, we have extended the applicability of this technique to study roughness of some handmade silver nano particle (size ~ 87 nm) impregnated and without impregnated paper sheets. Literature review shows that surface roughness from speckle pattern can be measured in a number of ways [13,14]. Usually, measurement of surface roughness is done by calculating the root mean square value of 3D surface profile map [15]. This work uses temporal five step phase shifting ESPI technique [16,17] for calculating 3D phase map and subsequently 3D surface profile for calculation of surface roughness.

EXPERIMENTAL SETUP AND METHODOLOGY

FIGURE.1 shows the images of paper sheets used for the study. Description of Paper sheets shown in FIGURE.1 is listed in Table no. 1.

FIGURE.1: Paper sheets without nano-particles I) 90 GSM, II) 160 GSM and impregnated with nano particles III) 90 GSM, IV) 160 GSM.

TABLE.1: Specification of Paper sheets shown in FIGURE.1

Paper Sheet reference as shown in FIGURE.1	Specification (GSM= grams per meter square)
Sample A	Untreated Paper Sheet (90 GSM)
Sample B	Untreated Paper Sheet (160 GSM)
Sample C	Silver Nano Particles (~87 nm) treated paper sheet (90 GSM)
Sample D	Silver Nano Particles (~87 nm) treated paper sheet (160 GSM)

FIGURE.2 shows the schematic of ESPI technique. He-Ne laser light (λ=632.8 nm) was used for the experiment. He:Ne laser beam gets split into two after hitting the beam splitter. One beam was used to illuminate the object surface which in this case is paper sheet, in the full-field manner via spatial filtering assembly. Illumination of the sheet gives rise to speckle pattern which carries information regarding the surface of the paper sheet. Generated speckle pattern was then collected and diverted using a mirror towards digital camera for recording. Second beam after multiple reflections to match the path length with the first beam passes through polarizer and diffuser plate to form reference speckle pattern. Object and reference speckle patterns superimpose onto each other to form speckle interferogram. Example of such speckle interferogram is as shown in inset of FIGURE. 2. Mirror M_1 was mounted on the calibrated optical phase shifter which is based on piezo electric effect [18]. Digitally filtered five phase shifted speckle interferograms were recorded for their utilization in temporal five step phase shifting method of ESPI [19]. Using the temporal five step phase shifting method of ESPI and unwrapping algorithms [20], unwrapped phase map and subsequently 3D surface map were evaluated. Example of unwrapped phase map is as shown in FIGURE.3.

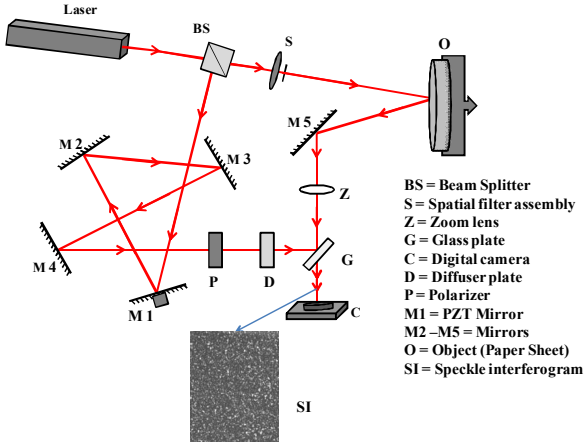

FIGURE.2: Schematics of Electronic Speckle Pattern Interferometer.

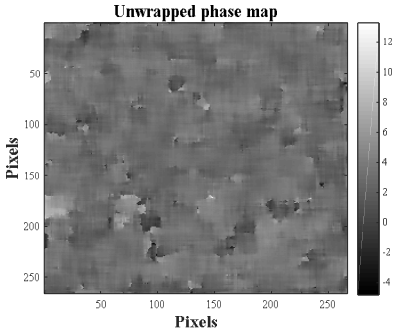

FIGURE.3: Unwrapped phase map.

RESULT AND DISCUSSION

Using the unwrapped 3D phase map, surface profiles of all paper sheets were calculated [17]. FIGURE.4 shows 3D surface maps and contour maps of all the paper sheets (of FIGURE.1) used.

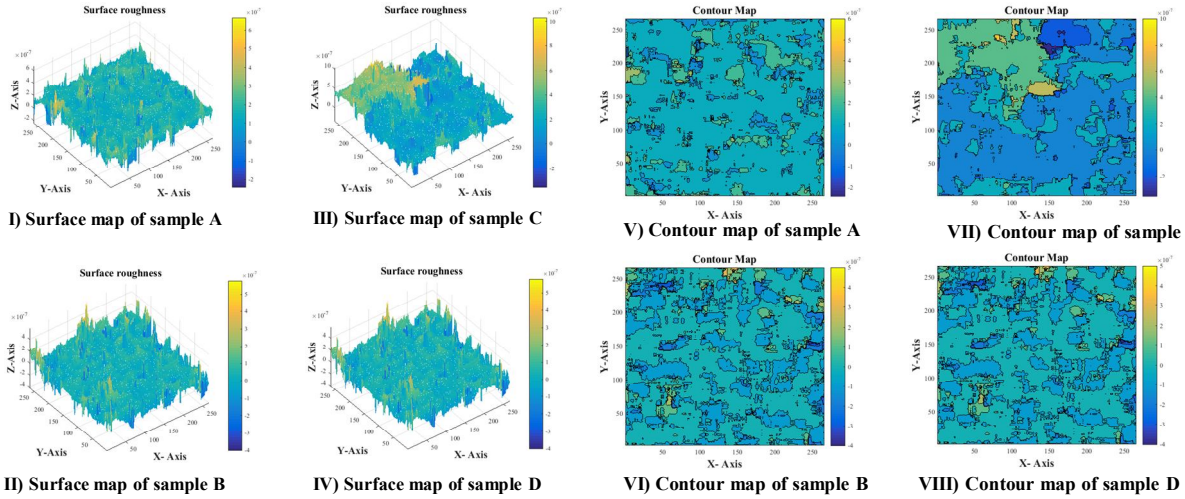

FIGURE.4: Surface profiles of paper sheet Sample I) A II) B III) C and IV) D. Corresponding Contour maps of paper sheet Sample V) A VI) B VII) C and VIII) D.

3D surface profiles of paper sheet samples A, B, C, D are as shown in FIGURE. 4I, II, III and IV and corresponding contour maps are as shown in FIGURE. 4V, VI, VII and VIII respectively. We have compared surface profiles and contour maps of paper sheets with and without nano particles for the same GSM (grammes per meter square) number. Hence Sample A is compared to C and Sample B is compared D. It indicates towards increase in roughness. To confirm it, we then evaluated root mean square value from surface profile maps. Root mean square values represent surface roughness of the paper sheets. Root mean square (R_{rms}) can be calculated using equation (1) [21],

$$R_{rms} = \left\{ \frac{1}{MN} \sum_{j=1}^{N} \sum_{i=1}^{M} \left[z(i,j) - \langle z(i,j) \rangle \right]^2 \right\}^{1/2} \qquad ---(1)$$

Where, z (i, j) is the surface profile values and <z (i, j)> represent its average. Surface roughness values calculated using this equation is listed in Table 2.

TABLE.2: Surface roughness values of Paper sheets shown in FIGURE.1

Sample Name	Specification	Surface roughness
Sample (A)	Untreated Paper Sheet (90 GSM)	150 nm
Sample (B)	Untreated Paper Sheet (160 GSM)	100 nm
Sample (C)	Silver Nano Particle treated paper sheet (90 GSM)	220 nm
Sample (D)	Silver Nano Particle treated paper sheet (160 GSM)	130 nm

From Table no. 2, it seems that after impregnated with silver nano particles, surface roughness of paper sheet increases.

CONCLUSION

Surface roughness of paper sheets were successfully evaluated using ESPI technique. Surface and contour maps shows increase in surface roughness for samples with silver nano particles compared to samples without them. Quantitatively surface roughness value evaluated for all the sheets used. It indeed shows increase in surface roughness for treated samples. Such silver nano particle treated paper sheets can be potentially useful as a water filter and in food packaging due to its antimicrobial property.

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