Enhancement of Antibacterial Efficiency of Face Masks Using Metal Nanoparticles

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Abstract

In this study, the antibacterial activity of commercial face masks made from polypropylene against gram-negative and positive bacteria was enhanced by dipping in gold nanoparticle (Au NPs) prepared in water using simple chemical precipitation route. The XRD for mask sample shows the typical diffraction lines of polypropylene for untreated mask, compared to samples soaked in the Au NPs suspensions at different concentrations which showed small peaks of gold structure. These diffraction peaks increased in intensity with the concentration of Au NPs in the samples. The strain-stress study shows slightly increasing the sample strength with increasing the Au NPs concentration, while the maximum strain reduced. The antibacterial efficiency of mask soaked in the Au NPs displays a decent inhibition zone toward E. coli and S. aureus bacteria, of diameter about 2.4 cm, and 2 cm respectively. The variation in efficiency of killing comes from the different nature of the composition of these two species.

Keywords: Au NPs, antibacterial, precipitation method.

Introduction

The immense impact of the COVID-19 pandemic on world health has prompted substantial research, including material-related research, to address the pressing concerns in prevent disease infectious. [1]. The pandemic exposed the flaws of commercial face masks that lack anti-bacterial properties and just serve as a filter tissue, whereas surgical masks offer an additional feature for bacterial and virus filtering based on the electrostatic charges of the masks, which dissipate after eight hours, resulting in a considerable drop in protection effectiveness [2]. The requirement to use protective masks for an extended time made it necessary to add new specifications to commercial face masks such as antibacterial efficacy against pathogens [3]. Since of the high resistance of some pathogens towards antibiotics, it prompted us to think of using nanoparticles as an alternative or supportive antibacterial agent [4], [5].

One of the most well-known substances in the manufacture of commercial face masks is polypropylene (PP) [6]. It is a synthetic resin extensively used in different plastic products. It is also spun into fibres [7]. Recently, nanotechnology has played a key role in the advance of smart fabrics and is considered the new generation with greater filtration and antibacterial efficiency [8].

Silver nanoparticles are among the most studied materials in this field for their antibacterial activity against a variety of pathogenic bacteria [9]. Also, Au NPs have chemical and photoelectric properties that make them of interest for many research and applications in biology and medicine for diagnostic, phototherapy and therapeutic uses or as an antibacterial [10]. Various techniques for construction of nanoparticles were revealed in the literature review, such as laser ablation [11], and chemical precipitation methods [12].

Numerous studies focused on increasing the antibacterial efficiency of face mask [13]. Gu et al. (2021) [14] studied the prepared and antimicrobial efficacy of Au NPs they found that the antibacterial effects are directly related to particle size, dispersibility, and surface modification by different reactions.

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Kumar et al. (2021) [3] improved the nonwoven fibers in face mask by using spray nozzles to add nanocoating hybrid copper nanoparticles (CuNPs) to increase its hydrophobicity for repelling water droplets. The resultant surface exhibited photocatalytic and photothermal capabilities for antibacterial effect, allowing the masks to be reused and self-sterilized.

In this work, we aimed to advance the antibacterial properties of commercial masks with gold nanoparticles prepared by precipitation method.

Experimental

Gold chloride trihydrate ($HAuCl_4.3H_2O$) of 99.9 % purity (Merck) as precursor and sodium tricitate (PubChem) were used in our experiment without any other purification. 0.005 gm of gold chloride salt dissolved in 50 ml DW and 0.5 gm of sodium tricitate dissolved in 50 ml DW. The first solution heated to about the boil point then the sodium tricitate solution added drop-wise to the solution till convert to red color.

The crystalline structure of a commercial face mask sample prepared from polypropylene and the effect of treatment with Au NPs on its structure were examined using X–ray diffraction system (Shimadzu XRD 6000). The source of radiation was Cu (Kα), the current was 30.0 mA and the voltage was 40 kV. The scanning angle 2θ was varied within the range (5°-60°) and speed of 5.00 (degree /min). Tensile tester model (LARYEE WDW-50) was used to study the mechanical properties of the mask samples before and after treatment with Au NPs at different concentrations. The antibacterial properties of the soaked mask in AuNPs suspension, compared with untreated samples, were assessed against two type of bacteria of gram-negative and gram-positive (Escherichia coli and Staphylococcus aureus). The mask samples were put onto the agar contain the targeted bacteria and incubated for 24 hours at 37° to study the inhibition zone around the samples.

Results and discussions

polypropylene (PP) polymer fibers is the basic material in the manufacture of most surgical masks. Figure 1 shows the XRD of samples taken from a mask before treatment compared to samples rinsed in suspensions of gold nanoparticles of different concentrations. The examination shows the typical peaks of PP which are clearly appeared at the diffraction angles of 13.8985, 16.7384, 18.3161, 21.3454 and 25.2582° that correspond to the diffractions from crystalline planes with Miller's indices of (110), (040), (130), (111), and (060) respectively. The preferred direction of growth was along (110). This result agrees well with previous studies [15].

The samples treated with gold particles and dried at 60 °C showed an enhancement of the crystallization of the samples as the intensity of the PP peaks increased. On the other hand, small peaks of gold particles appeared at a diffraction angle of 38.3219 ° and 44.8537 °, which matches to the crystal planes of (111) and (200) for Au NPs, respectively, matched with standard card No. 96-901-2431. These diffraction peaks increased in intensity with the increase in the concentration of gold in the samples.

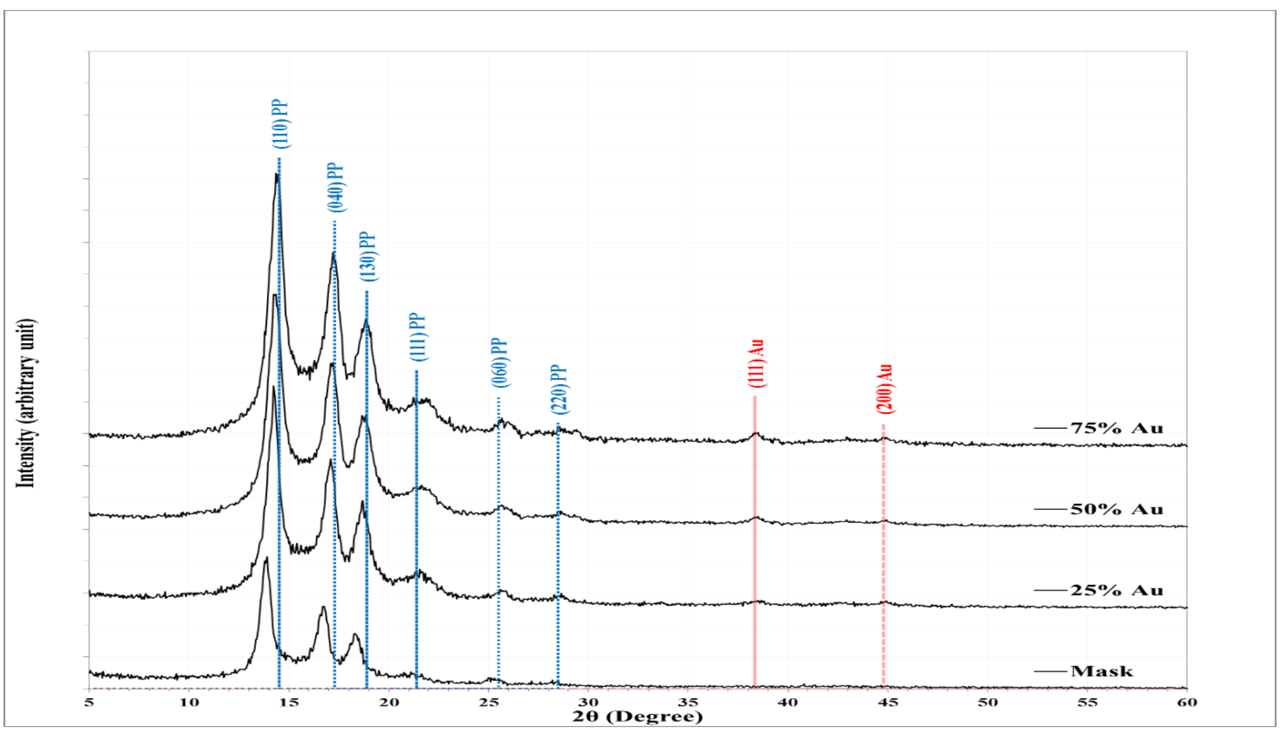

Figure 1: XRD patterns for pure mask and decorated samples with Au NPs at different concentrations.

Figure 2 illustrates the strain-stress curves for free mask sample and that decorated with Au NPs at different concentrations. All patterns show typical stress–strain behavior [16], which composed two regions start with the elastic one which is nearly linearly dependent, end at the elastic limit at about 0.15% strain. The second region of non-linear behavior, called plastic region, end at the fracture point. Young's Modulus is measured from the slope of the linear part. The mechanical properties depends on intrinsic characteristics of the polymers and due to the mechanical behavior of hydrogen bonds, which affect the mechanical behavior of the final composites. It seems that the tensile strength slightly increased with increasing the Au NPs concentration, while the maximum strain reduced indicating on reducing the sample elasticity.

Figure 3 shows the variation of Young modulus and maximum elongation with Au NPs concentration for mask samples. It is clear that the Young modulus increased from 36.5 to 61.7 MPa, while the maximum elongation reduced from 117 to 92% with increasing the used Au NPs suspension from 0 to 75% of the initial concentration of the as prepared suspension.

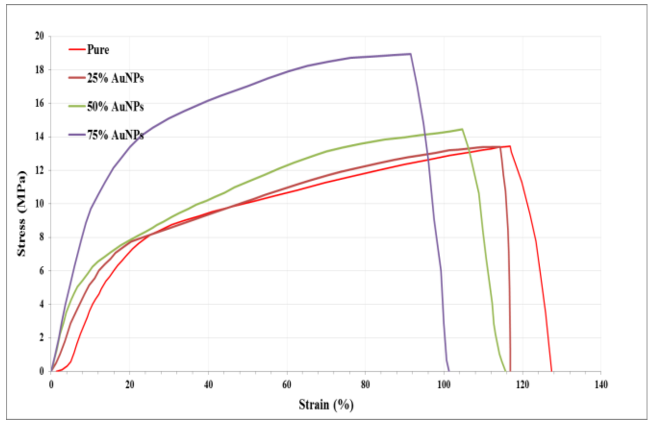

Figure 2: Stress-strain curve for pure mask and decorated samples with Au NPs at different concentrations.

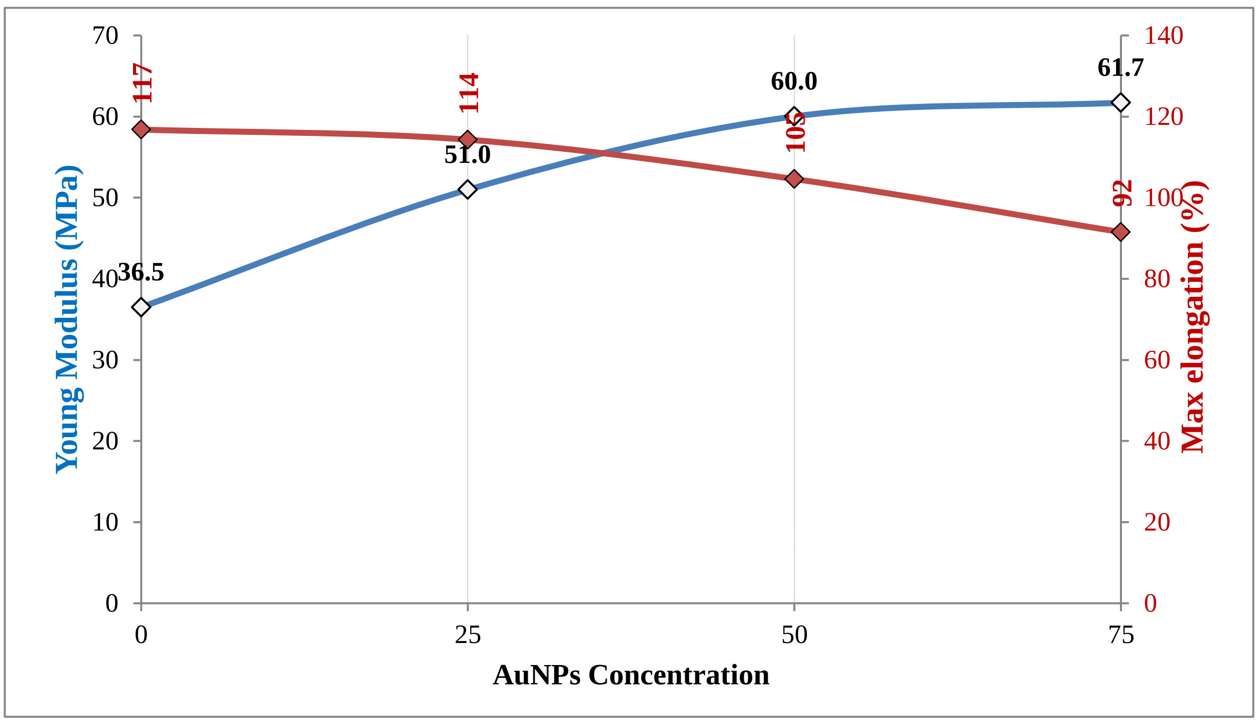

Figure 3: variation of Young modulus and maximum elongation for mask samples with Au NPs concentration.

Figure 4 shows the antibacterial activity test of the mask samples soaked in AuNPs suspension put onto the agar surface sprayed with Escherichia coli and Staphylococcus aureus bacteria compared with control samples. The image displays a decent antibacterial efficiency against both types of bacteria, while no inhibition zone appeared around the control samples. The activity was more effective against Staphylococcus aureus, which shows an inhibition zone of diameter about 2.4 cm, while the inhibition zone with the Staphylococcus aureus of diameter 2 cm. The reason for the difference in the efficiency of killing comes from the different nature of the composition of these two species [16]. The mechanism of antibacterial for Au NPs is chiefly by altering cell membrane permeability by decline its metabolic activities, or by inhibit the ribosome subunit for tRNA. Furthermore, the AuNPs do not produce any ROS [17], [18]. The result indicates that the mechanism of killing does not depend primarily on the nature of the cell wall, as it is weaker for the gram-negative bacterial type. So, it is likely that the interaction of gold particles with RNA and disruption of vital functions is the main cause.

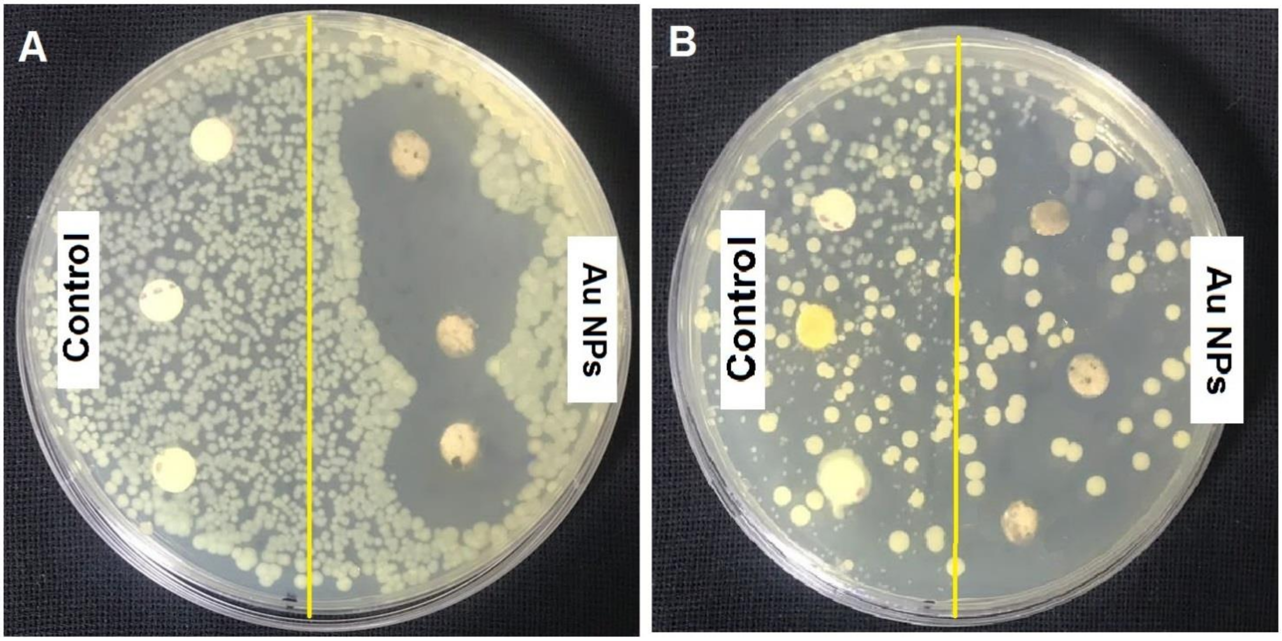

Figure 5: Antibacterial activity test of the mask samples soaked in AuNPs suspension against (A) E.Coli, and (B) S.aureus pathogenics

Conclusions

The study showed the efficiency of the rote of soaking face masks in a gold suspension, prepared by a simple method, to be antibacterial against harmful microbes E.Coli, and S.aureus. The antibacterial test showed a good killing of gram positive bacteria, while, has the lowest activity against the gram-negative bacteria E.coli,. This result indicates that the mechanism of bacterial inhibition on the treated mask containing Au NPs mainly depends on the accumulation of gold particles inside the cell and their binding with RNA, which leads to disruption of vital functions. The result supports the possibility of extend wearing the masks for a longer period. So, this smart nano-assisted masks is candidate particularly for use in new avenues to avoid the spread of infectious diseases.

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