Gamma irradiation effects on the electrical properties of gold nanoparticles

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Abstract: Gold nanoparticles (AuNPs) offer a great promising in biomedical applications and their size has been shown to be important parameters that affect the particles uptake and cellular imbibition. The presented dielectric data indicates that AuNPs have well characteristic dispersion in the alpha relaxation region. The presented work aims to characterize and improve the quality control of AuNPs, define the benefit combination effects of size and gamma irradiation on the properties of AuNPs dielectric relaxation spectroscopy.

Keywords: Gold nanoparticles, dielectrics relaxation, gamma irradiation.

INTRODUCTION

Aunique property ischaracterizing metal nanoparticles such as catalytic, electronic, magnetic, and optical properties which they are different from those of bulk metals (Klaus *et al.,* 2001). This could result in interesting new applications that could potentially be utilized in the biomedical sciences and areas such as optics and electronics (Klaus *et al.,* 2001). Gold nanoparticles (AuNPs) are some of the most widely utilized nanomaterials in bioimaging and biomedical therapeutics due to their intense surface plasmon resonance (Jain *et al.,* 2007; Sperling *et al.,* 2008).In the last few decades gold nanoparticles (AuNPs) have been used in radiation therapy (Mello *et al.,* 1983, Mesa 1999; Hainfeld *et al.,* 2004 & 2006; *Chien et al.,* 2007). A biologically effective dose enhancement was found when gold micro spheres used *in vitro* and *in vivo* (Herold *et al.,* 2000, Cho S, 2005). Enhancing radiation therapy is found when small AuNPs are used rather than larger ones (Hainfeld *et al.,* 2004). Combination treatment of AuNPs along with radiation give an effective tumor control than that of x-rays and AuNPs alone. Moreover, the results indicate that when kV x-ray beams are used, AuNPs reduce the level of the required dose. This is a very important consideration to reduce the healthy tissue exposure and it is the first concern in radiation therapy procedures (Mesa, 1999; Hainfeld, 2004 & 2006; Chien *et al.,* 2007). Recently, due to their strong photoelectric absorption and emission of second electron caused by gamma or X-ray irradiation which accelerate DNA strand breaks, AuNPs have been considered as a type of radio sensitizer in radiotherapy (Kreibigand V, 1995; Mirkinand R, 1997; Rampi *et al.,* 1998).

Dielectric spectroscopy deals with dielectric properties measurements of a medium, which based on the interaction of an external field at different frequencies with the medium electric dipole moment often expressed by medium permittivity. They also determine the behavior of the materials when subjected to high frequency (Markx and Davey, 1999; Luigi *et al.,* 2007). Dielectric properties are related to the molecule ability to be polarized when exposed to an electromagnetic field. If any dielectric material is introduced between the two plates, the corresponding response to a sinusoidal field will be characterized by dielectric properties (dielectric permittivity ε, and conductivity σ) which vary with frequency. The charge and current densities induced in response to an applied electric field is an example of an idealized parallel plate. Since, the polarizability of the materials depends on the structure and molecular properties, dielectric measurements can provide good information about these terms.

Dielectric characterization of many biological materials have been presented by the authors to obtain a useful interpretation about structural changes when they undergoes to internal or external effects (Ghannam *et al.,* 2002; Ghannam and Mady, 2012).

The objective of the present experimental work is to study the potential effects of gamma radiation on the AuNPs electrical parameters of different sizes in the frequency range of 20 Hz to 3 MHz.

MATERIALS AND METHODS

AuNPs with nominal sizes of 5nm and 50nm were purchased from Products MKN (Products MKN-Au-05; MKN-Au-050, MK Impex Corp, Canada).

Gamma irradiation facility

The studied samples were irradiated by 60Co gamma rays presented at King Saud University, College of Science, Kingdom of Saudi Arabia with 87Gy/h dose rate at the

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center of the chamber. In the present work, gold nanoparticles samples received irradiation doses in the range of 10 to 100Gy.

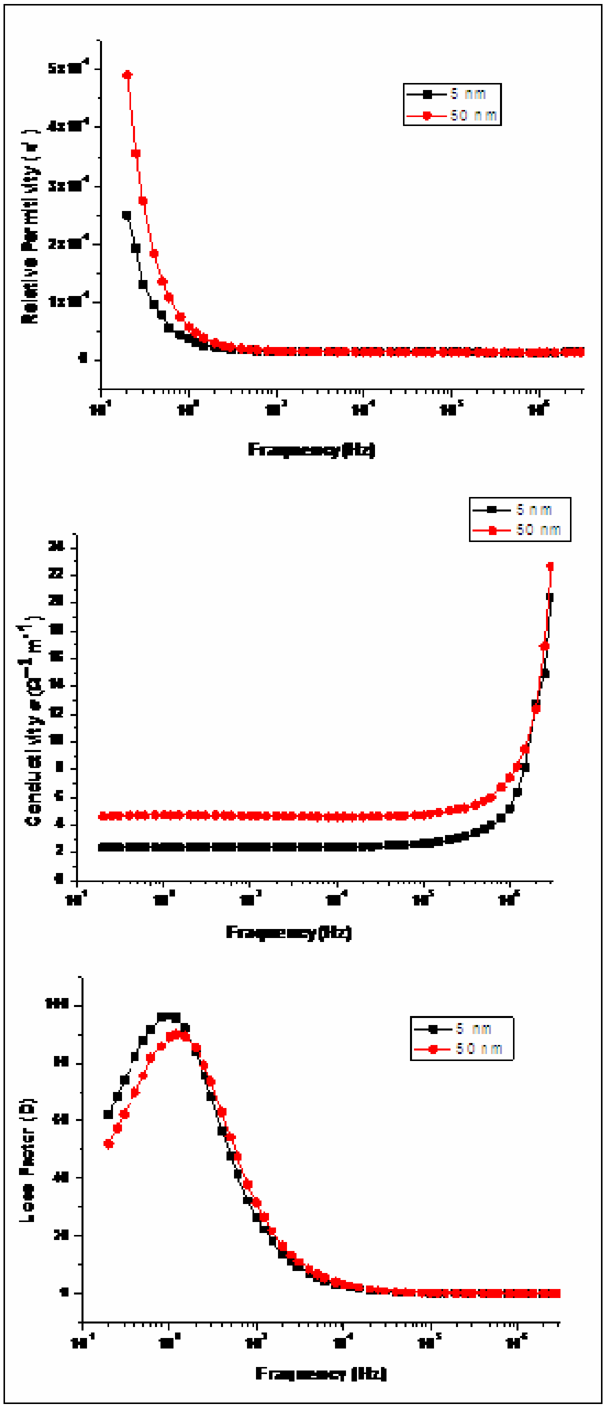

Fig. 1: Relative permittivity ε', Electrical conductivity σ and Loss factor D as a function of the applied frequency in the range of 20Hz to 3MHz for unexposed (control) AuNPs of 5 & 50nm.

Electrical parameters

The electrical parameters were measured using a WAYNE KERR precision component analyzer, model 6440 B (UK) in the frequency range of 20Hz up to 3MHz. The conductivity cell has a cell constant of $1 cm^{-1}$. AuNPs suspensions placed between the two parallel plate capacitor of the conductivity cell. The capacitance (C) and resistance (R) were measured in the frequency range mentioned and were used to calculate the real (ε') and imaginary part (ε') of the complex permittivity, Conductivity (σ) and relaxation time (τ) using the equations previously published (Abdelhalim *et al.*, 2011;Ghannam *et al.*, 2002).

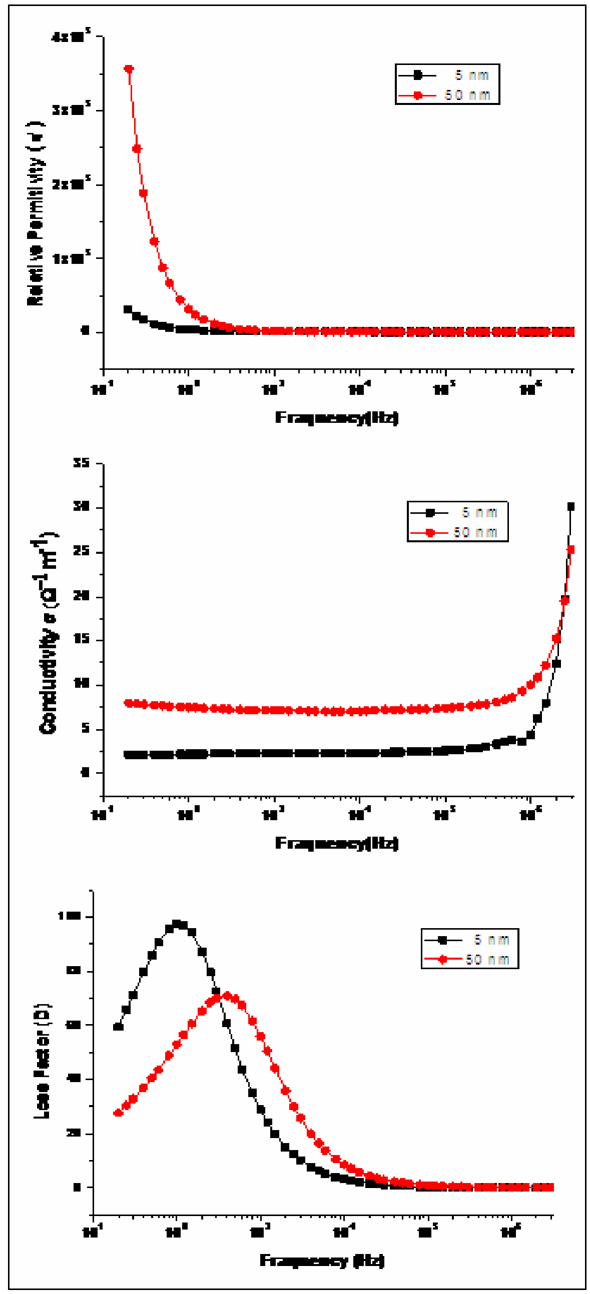

Fig. 2: Relative permittivity ε', Electrical conductivity σ and Loss factor D as a function of the applied frequency in the range of 20Hz to 3MHz for AuNPs of 5 & 50nm exposed to gamma irradiation of 10Gy.

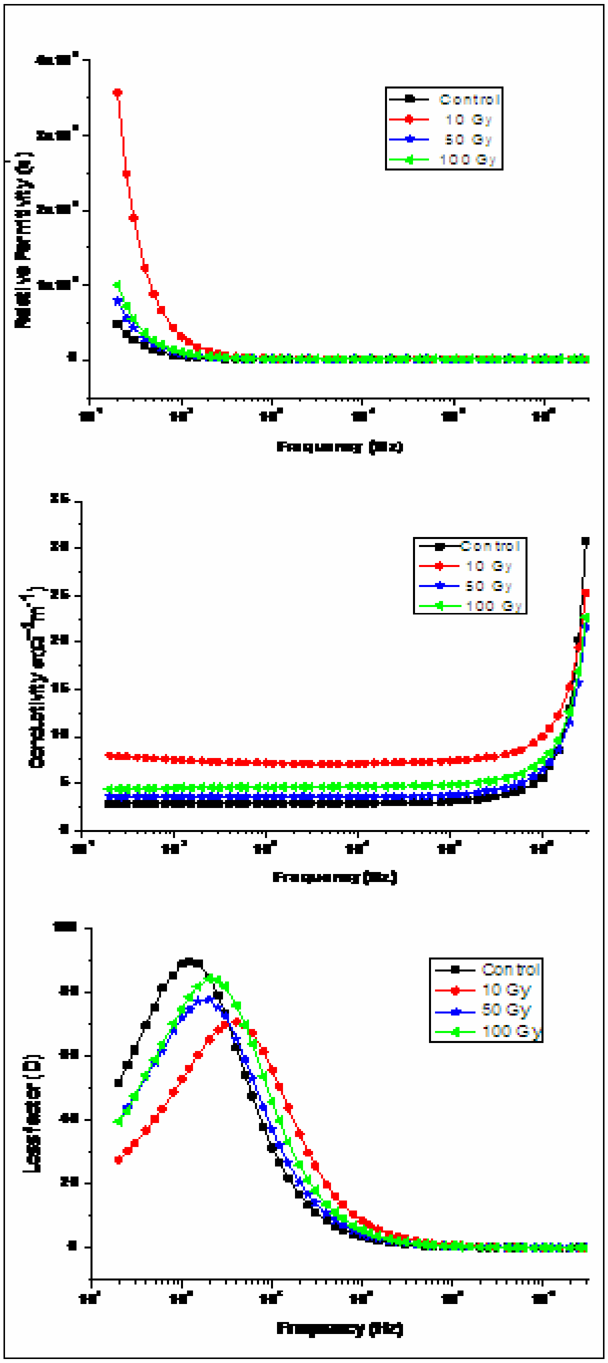

Fig. 3: Relative permittivity ε', Electrical conductivity σ and Loss factor D as a function of the applied frequency in the range of 20Hz to 3MHz for AuNPs of 50nm exposed to gamma irradiation of 0 (■), 10 Gy (●), 50 Gy (*) and 100Gy (▲).

RESULTS

Fig. 1(a-c) shows the variation of relative permittivity (ε') and conductivity (σ) and loss factor (D) respectively with frequency for different AuNPs sizes 5 and 50nm at RT.

Fig. 2(a-c) shows the relative permittivity ε', electrical conductivity σ and loss factor D as a function of the applied frequency in the range of 20Hz to 3MHz for AuNPs of 5 & 50nm exposed to gamma irradiation of 10 Gy. Fig. 3(a-c) shows the relative permittivity ε', electrical conductivity σ and loss factor D as a function of the applied frequency in the range of 20Hz to 3MHz for AuNPs of 50nm exposed to gamma irradiation of 0, 10, 50 and 100Gy. The presented dielectric data indicates that the AuNPs have well characteristic dispersion in the alpha relaxation region**,** which is can be identified as anomalous frequency dispersion.

DISCUSSION

The rapid decrease in ε' may be attributed due to the orientation of AuNPs dipoles along the applied field in the low-frequency range**.** In the higher frequencies the dipoles will hardly be able to orient themselves leadingε' to have a constant values. On the other hand, ε' increases as AuNPs size increases (fig. 1 a). Moreover, the conductivity has higher values for 50nm than that of 5 nm (fig. 1b).

The variation of loss factor D (fig. 1c) indicates that AuNPs undergoes a relaxation process. The relaxation time was found to be decreased as the AuNPs size decreased. It was found to be 1.3±0.06 ms and 1.6± 0.06ms for 5and 50 nm sizes respectively**.** A data are in agreement with those of Shahid *et al.*, (2004) which concluded that small nanoparticle have faster relaxation times than that of conventional micro particle. This may be attributed to the increase in the charges aggregation within the medium which is confirmed by the conductivity results. Mariappan and Govindaraj (2002) attributed the variation in the dielectric constant and the dielectric loss with frequency to the formation of a space-charge region at the electrode and sample interface which explained in terms of ion diffusion.

Moreover, the dielectric properties of AuNPs of 5 and 50 nm sizes were measured after their exposure to different gamma dose of 10, 50 and 100Gy. It is clear that both ε', and σreaches a maximum value at 10Gy irradiation dose. It was established that the magnitude of dielectric constant counter ion polarization of the studied molecules (Polk and Postow, 1996; Pethig, 1979). Polarization effect is repeals the higher frequency effect on the dielectric constant and so the decrease in the value of the dielectric constant of the system is observed. Therefore, gamma irradiation can alter the counter ions polarization and so strongly affects the ionic charge distribution. There is an increase in the AuNPs conductivity σ (figs. 2b; 3b) due to irradiation that may attributed as an increase **in** the distribution of the surface charge density of the irradiated molecules and the increase of the charge transfer through the medium.

Table 1: The dielectric increment Δ, the relaxation frequency f_c the relaxation time and Cole-Cole parameter α, for all studied gold nanoparticles samples with size 5 and 50nm.

	AuNPs 5nm				AuNPs 5nm			
Exposure Dose (Gy)	Δ x10^4	f_c (Hz)	(ms)	α	Δ x10^4	f_c (Hz)	(ms)	α
Control	2.27	100	1.59	0.38	4.73	120	1.32	0.44
10	2.99	100	1.59	0.35	35.39	400	0.39	0.33
50	1.81	60	2.65	0.44	7.75	200	0.79	0.41
100	2.06	80	1.99	0.42	9.84	200	0.79	0.40
200	4.14	100	1.59	0.33	14.26	200	0.79	0.44

CONCLUSION

The dielectric data of the studied AuNPs indicates that they are characterized by a dielectric α dispersion. The variation in the dielectric parameters due to irradiation can be attributed to the change in the relaxation of the AuNPs. There are relatively significant increases of both ε' and conductivity σ according to the irradiation dose.

Moreover, ε' and σhad higher values as size of the AuNPs increases. AuNPs of 5 nm size are preferable to use them in tumor therapy. Combination between AuNPs and gamma irradiation can be used as a powerful conjunction system that may give us the benefit of them and so will aid in improving the clinical treatment protocol and fights against serious diseases.

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