UJAT
Universidad Juárez Autónoma de Tabasco
"Estudio en la duda. Acción en la fe"

JEEOS

Journal of Energy, Engineering Optimization and Sustainability

2026



Vol. 10 Núm. 3 (2026)

Reserva de Derechos al Uso Exclusivo

No. 04-2026-050410175100-102. ISSN: 2448-8186

Esta revista está citada en:

Sistema Regional de Información en Línea para Revistas Científicas de América Latina y el Caribe, España y Portugal LATINDEX.http://www.1atindex.unam.mx/ JOURNAL OF ENERGY, ENGINEERING OPTIMIZATION AND SUSTAINABILITY, Vol 10, No. 3, Año 2026, es una publicación continúa editada por la Universidad Juárez Autónoma de Tabasco, Av. Universidad S/N, Zona de la Cultura, Col. Magisterial, C.P. 86040, Villahermosa, Tabasco, México. Tel. (+52) (933) 358 1500 Ext. 5040, https://revistajeeos.ujat.mx/JEEOS/es/, Email: jeeos@ujat.mx. Indizada en LATINDEX. Editora responsable: Laura Lorena Díaz Flores. Reserva de derechos al uso exclusivo No. 04-2026-050410175100-102, ISSN: 2448-8186, ambos otorgados por el Instituto Nacional del Derecho de Autor. Responsable de la última actualización de este número: Pauly González Mayo, Universidad Juárez Autónoma de Tabasco, Av. Universidad S/N, Zona de la Cultura, Col. Magisterial, Centro, Tabasco. C.P. 86040. Fecha de última actualización, 15 de diciembre 2026.

This work is licensed under a Creative Commons Attribution- NonCommercialShareAlike 4.0 International License.

Índice Vol. 10 Núm. 3 (2026)

JEEOS

UJAT
Universidad Juárez Autónoma de Tabasco
"Estudio en la duda. Acción en la fe"

Índice Vol. 10 Núm. 3 (2026)

Transformación material en la vivienda chontal, caso de estudio: Huimango, Cunduacán, Tabasco 1-12
Campos-de Dios P.C.[1*], Govea-Ek A.[1]

Inhibición de corrosión en acero API 5L-X52 mediante extracto etanólico de *Tradescantia spathacea Sw* 13-25
Estrada-Hernández G. V., Figueroa-Ramírez S.J.[*], Sierra-Grajeda J.M.T., Santis Espinosa L.F., Benavides O., De la Cruz-May L

Efecto de las nanoparticulas metálicas sobre el crecimiento de la microalga *Coelastrella sp.* para la producción de biocombustible 26-37
Santis-Espinosa L.F[1*], Figueroa-Ramírez S.J.[1], Vargas-Estrada L.[2], López-Vidaña E.C.[3]

Influence of dopant material on a silicone polymer subjected to low-pressure air plasma treatments 38-52
Alarcón-Hernández F.B.[1]*, Fuentes-Albarrán M. del C.[1], Paredes-Olguín M.[2], Avelar-Domínguez F.[1], Gadea-Pacheco J.L.[1], Sandoval-González A.[3]

Cambio en la producción de potencia empleando Na_2SO_4 en el cátodo de una celda de combustible microbiana 53-60
Fuentes-Albarrán M. del C.[1]*, Alarcón-Hernández F.B.[1], Cornejo-Tapia C.P.[1], Sandoval-González A.[2]

Estudio exploratorio del contenido de etanol en la pulpa de la T*hevetia peruviana* (Pers.) K. Schum en Yucatán, México 61-79
Koh-Echeverría L.E.[1], Amado-Méndez K.[2], Díaz-Ballote, L.F.J.[2], Herrera-Zamora, D.M.[2]*

Determinación de carbohidratos por HPLC: comparación de detectores UV-Vis *vs* índice de refracción 80-93
Fernández-Orozco I.V.[1], Grijalva-Haro M.I.[2], Madrigal-Diaz S.C.[1], Ojeda-Morales M.E.[1], Díaz-Reyes C.C.[1], García-López S.[1], Juárez-Zirate S.J.[3]*

Efecto de un plasma pulsado de aire en las propiedades superficiales de caucho butílico 94-103
Alarcón-Hernández F.B.[1]*, Fuentes-Albarrán M. del C.[1], Garay-Galicia J.A.[1], Sandoval-Gonzáles A.[2]

Estudio del tiempo de fraguado en pastas de cemento con sustitución parcial por biocemento de ostión 104-116
Segundo-Díaz T. de J.[1], Mora-Ortiz R.S.[1]*, Díaz-Alvarado S.A.[1], Ramón-de los Santos C. [2]

Estudio teórico de un captador solar de aire con y sin material de cambio de fase 117-128
Álvarez-Alor B.[1*], Cruz-Valdez J. A. [2], Montalvo D. [3], López-Santos F.[1], Alvarado-Méndez P. E.[4], Zetina-Ríos I. I.[5].

Índice Vol. 10 Núm. 3 (2026)

Influencia de material dopante en un polímero de silicón sometido a tratamientos de plasma de aire a baja presión

Influence of dopant material on a silicone polymer subjected to low-pressure air plasma treatments

Alarcón-Hernández F.B.[1]*, Fuentes-Albarrán M. del C.[1], Paredes-Olguín M.[2], Avelar-Domínguez F.[1], Gadea-Pacheco J.L.[1], Sandoval-González A.[3]

[1]Escuela de Estudios Superiores de Xalostoc de la Universidad Autónoma del Estado de Morelos
Avenida Nicolas Bravo s/n, Xalostoc CP 62725 Ayala, Morelos, México.
[2] Universidad Politécnica del Valle de México
Avenida Mexiquense, esq, Av. Universidad Politécnica s/n, CP 54910 Fuentes del Valle, Estado de México, México.
[3]Centro de Investigación y Desarrollo Tecnológico en Electroquímica, S.C
Parque Tecnológico Querétaro SN, CP 76703 San Fandila, Querétaro, México.
*honorato@uaem.mx

Artículo Científico
Publicado: 15 de diciembre 2026

ABSTRACT

The effect of incorporating a dopant material into a silicone polymer was analyzed when exposed to low-pressure air plasma. Square composite samples of silicone rubber (Momentive RTV615) were used. Five undoped samples and five samples doped with fumed silica (SiO_2) nanoparticles (Aerosil R812) at a concentration of 1.0% of the total volume were used. The plasma was applied in a vacuum chamber (20 Torr) and generated (20 mA, 4000 V) using a high-voltage source (SPELLMAN SL600). Five plasma exposure times were considered (0.0, 1.0, 5.0, 10.0, and 15.0 min). In general, incorporating the dopant modifies the polymer's initial properties. It reduces changes in response to plasma treatments, attenuates degradation, stabilizes hydrophobicity, and moderates optical changes. The dopant is an effective option for controlling and optimizing the response of surface-modified polymers to plasma. The influence of its volume on the variables of interest remains to be analyzed.
Keywords: Percentage mass loss; hydrophobicity; transmittance; polydimethylsiloxane.

INTRODUCTION

The modification of polymer surfaces is highly relevant today due to its direct impact on key properties, including hydrophobicity, surface energy, adhesion, and chemical functionality. These modifications directly affect the advanced applications of these polymers across multiple areas of knowledge.

Polymers, while possessing attractive intrinsic properties (lightweight, elastic, and easy to process), are often chemically inert at their surfaces, which limits their performance in applications that require controlled interaction with liquids or other materials [1]. Among the most studied polymers is silicone, especially in the form of silicone rubber. This polymer is notable for its natural

CC BY NC SA
Registro ISSN 2448-8186
DOI:10.19136/Jeeos.a10n3.6695

hydrophobicity, making it useful for protective and insulating coatings, but it also poses challenges when surfaces with greater affinity or surface functionality are desired [2].

One strategy considered for adjusting the functional properties of polymers involves incorporating dopants into the polymer matrix of interest. The addition of nanoparticles or dopants can significantly alter the properties of the resulting composite, including hydrophobicity, electrical conductivity, and mechanical response. In the case of silicon doped with metal oxide nanoparticles (e.g., TiO_2, CeO_2, or carbon black), recent studies have observed variations in surface topography and wetting behavior that can even lead to superhydrophobic states when combined with appropriate micro- or nanostructural roughness [2-6].

Concurrently, low-pressure plasma treatments have proven effective for modifying the surface characteristics of polymers without affecting their bulk properties. Non-thermal plasmas generate reactive species (radicals, ions, electrons) that interact with the polymer surface, causing bond breakage, the introduction of polar functional groups, and, to some extent, the removal of contaminants; this leads to measurable changes in surface free energy and contact angle [7-9]. These studies have shown that air plasma treatment can modify the hydrophobicity of polymeric materials, rendering them more hydrophilic or hydrophobic, depending on the parameters used (exposure time, power, pressure) and the plasma gas composition.

The combination of polymer doping and plasma treatments opens a field in which not only can surface properties be adjusted, but also specific effects on the material's internal structure and its response to the plasma can be explored. Doped polymeric materials can exhibit changes not only in surface hydrophobicity but also in the distribution of functional groups and in the chemical response to plasma species, which can influence the stability of the modification and hydrophobic recovery over time [10]. Plasma functionalization studies indicate that incorporating oxygenated or fluorinated groups via reactive gases (oxygen, nitrogen, or fluorine-containing gases) can create highly functional surfaces with improved adhesion or increased water repellency [11].

Doping silicone polymers with low-pressure air plasma suggests a route to modify surface properties, especially for applications in smart coatings, biomedical devices, and sealing or encapsulation systems that demand optimized surface properties. Therefore, this study aims to determine the influence of a dopant on a silicone polymer after low-pressure air plasma treatment.

EXPERIMENTAL METHODOLOGY

Study Polymer. Square composite samples measuring 1.0 cm on each side and 0.05–0.06 cm thick were used. These samples were obtained from a larger polymer measuring 6.0 cm on each side and 0.3 cm thick, with a silicone rubber matrix (Momentive RTV615), as shown in **Figure 1**.

CC BY NC SA
Registro ISSN 2448-8186
DOI:10.19136/Jeeos.a10n3.6695

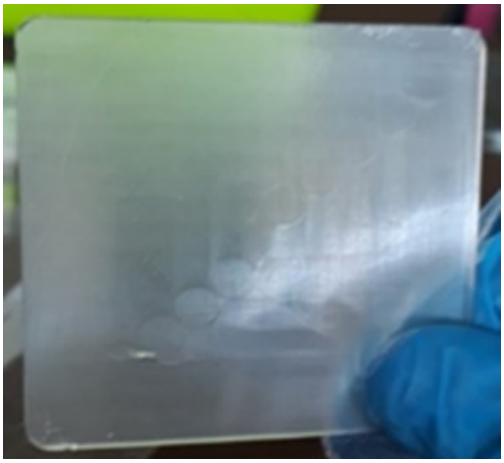


Figure 1. Figure 1. Doped polymer with dimensions of 6.0 cm per side and 0.3 cm thickness from which the study material was obtained.

Five undoped samples and five samples doped with fumed silica (SiO_2) nanoparticles (Aerosil R812) at a concentration of 1.0% by volume were considered. The initial polymer (doped and undoped samples) was prepared while the material was still in the liquid phase. For the doped samples, the dopant material was mixed using high-shear mechanical mixing (HS). Subsequently, the samples were consolidated by hot pressing (HP). All study samples were cleaned with ethanol one day before exposure to plasma.

Experimental setup. **Figure 2** shows a schematic of the experimental apparatus used. It consists of a hermetically sealed glass chamber, two aluminum electrodes (a tip and a rectangular base), a vacuum system (digital vacuum gauge: CPS, vacuum pump: LABCONCO), and a high-voltage power supply (SPELLMAN SL600).
The negative electrode is located at the bottom of the chamber, while the positive electrode is located at the top. The composite sample of interest is placed between both electrodes, so that it is directly exposed to the plasma generated during the treatment. Each sample is exposed to plasma for a specific time. After this time, the treatment is stopped, and the sample is removed.

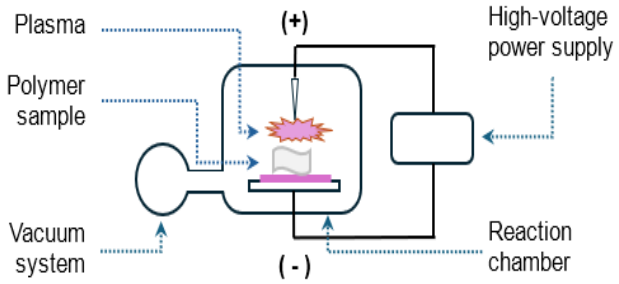


Figure 2. Schematic of the experimental device for plasma treatment.

Exposure of polymers to air plasma. The plasma treatments of the samples of interest consisted of exposing each polymer sample to low-pressure air plasma (20 Torr) for a specific time. The plasma generation parameters were fixed (20 mA, 4000 V), as was the distance between electrodes

Registro ISSN 2448-8186
DOI:10.19136/Jeeos.a10n3.6695

(1.0 cm). The variable that determined each treatment was the polymers' exposure time to the plasma, along with whether the material was doped or undoped. **Table 1** presents the values considered for each treatment.

Table 1. Plasma exposure time values used according to treatment

Sample	Exposure time (min)
Control sample	00.0
1	01.0
2	05.0
3	10.0
4	15.0

Measurement of variables of interest. The changes generated in the study samples due to the dopant and the exposure time to the plasma treatments were determined by measuring the change in mass (analytical balance: AE-ADAM, model PW254), hydrophobicity (sessile droplet technique, digital microscope: Black 1600X Microscope), and infrared transmittance (Alpha FITR spectrometer, Bruker Optics).

Specifically, hydrophobicity was determined by measuring the internal angle between the surface of interest and a droplet of distilled water (a small angle indicates a hydrophilic surface, a large angle indicates a hydrophobic surface), as shown in **Figure 3.**

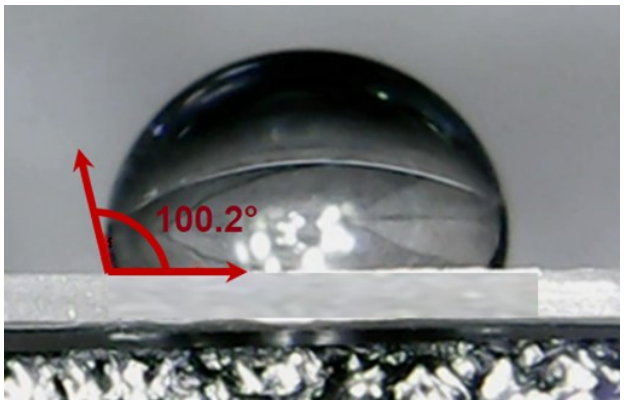


Figure 3. Measurement of the contact angle (hydrophobicity)

RESULTS

Exposure of the polymers to air plasma produced different effects in the doped and undoped samples, depending on the exposure time. The results for mass loss, changes in hydrophobicity, and infrared transmittance spectra for all samples are presented.

Percentage change in mass. **Figure 4** shows the behavior of the percentage change in mass of the doped and undoped samples of the polymer under study. It can be observed that, for both polymers, there is mass loss as a function of exposure time, regardless of whether the material was doped.

Registro ISSN 2448-8186
DOI:10.19136/Jeeos.a10n3.6695

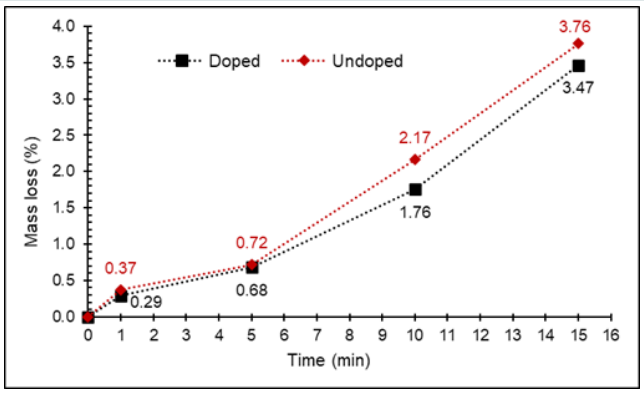


Figure 4. Percentage change in mass of the polymers of interest as a function of exposure time and the presence of the doping

In particular, it can be observed that both polymers (doped and undoped) showed greater mass loss as exposure time increased. However, for the doped material, the mass loss percentage was lower at all plasma exposure times (01.0, 05.0, 10.0, and 15.0 min). These results show that doping material inhibits the percentage of mass loss.

Hydrophobicity. The hydrophobicity of the samples (doped and undoped) exposed and unexposed to plasma was determined by measuring the contact angle formed between the surface of interest and the water droplet. The larger the measured angle, the greater the hydrophobicity.
Figure 5 shows the measured angle values for the respective materials studied.

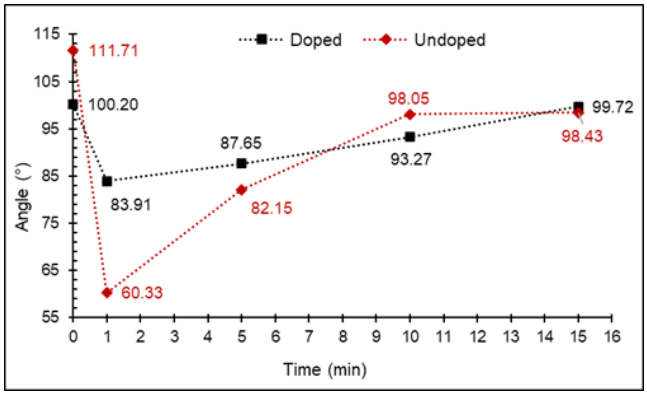


Figure 5. Angle measures as a function of exposure time to air plasma

From the graph, it can be observed that exposure to air plasma decreases the water contact angle in both polymers at all times, indicating reduced surface hydrophobicity, especially at short treatment times. The undoped polymer initially exhibits greater hydrophobicity and a more pronounced response to plasma, reaching a maximum reduction in contact angle after 1.0 minute of exposure. In contrast, the doped polymer shows a more moderate decrease, suggesting that doping limits or stabilizes the plasma-induced surface modification. At longer exposure times, a progressive increase in the contact angle is observed in both materials, approaching the initial values. Both doping and exposure time significantly influence the polymer's hydrophobicity.

Registro ISSN 2448-8186
DOI:10.19136/Jeeos.a10n3.6695

Infrared Transmittance. Figures 6 and **7** show the total transmittance spectra of the polymers under study (doped and undoped, respectively) after plasma exposure. Apparently, no difference is observed between the spectra for the different exposure times of each polymer.

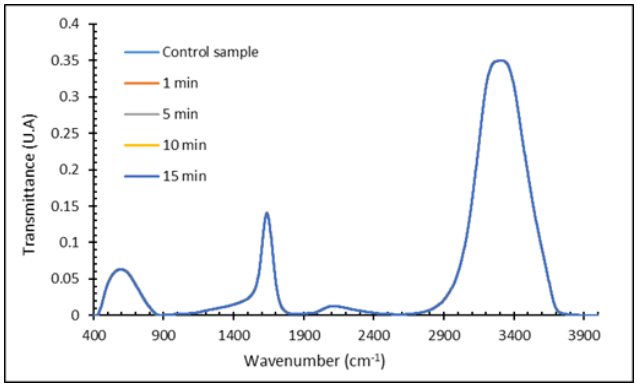


Figure 6. Infrared transmittance of the doped polymer after exposure to plasma for different times.

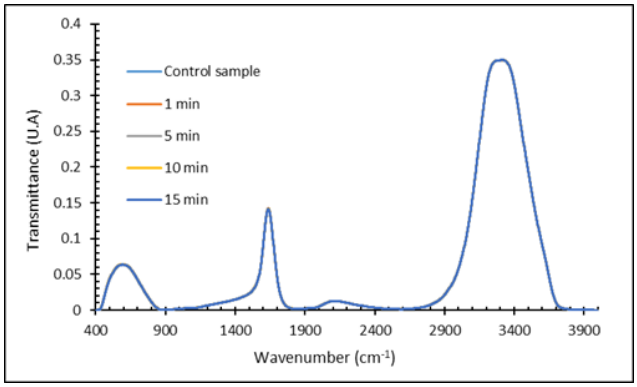


Figure 7. Infrared transmittance of the undoped polymer after exposure to plasma for different times.

An analysis of both figures (Figures 6 and 7) at wavenumbers between approximately 565 and 625 cm^{-1} and 1620 to 1650 cm^{-1} reveals different intensity behaviors, as shown in **Figures 8 and 9** (doped polymer) and **Figures 10 and 11** (undoped polymer).

When comparing the infrared transmittance intensity of the doped materials across different exposure times, both figures (**Figures 8 and 9**) show that the transmittance changes with exposure time. The highest transmittance is observed for the material exposed to the plasma for the shortest time (1 min). As the exposure time increases, the transmittance decreases until it approaches the value of the control sample.

For the undoped material **(Figures 10 and 11**), the control sample (0.0 min) exhibits the highest transmittance intensity in both intervals. In this case, transmittance decreases as plasma exposure time increases.

Registro ISSN 2448-8186
DOI:10.19136/Jeeos.a10n3.6695

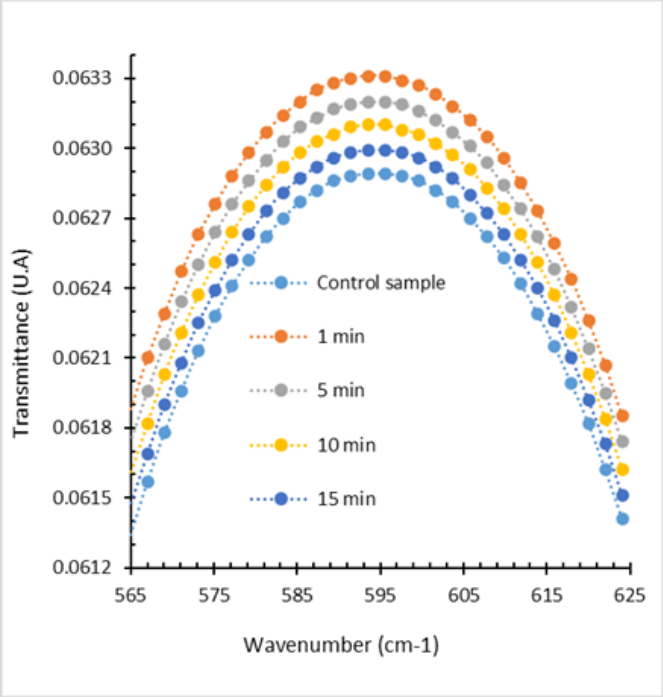


Figure 8. Infrared transmittance of the doped polymer after different plasma exposure times. Range (565 to 625 cm^{-1}).

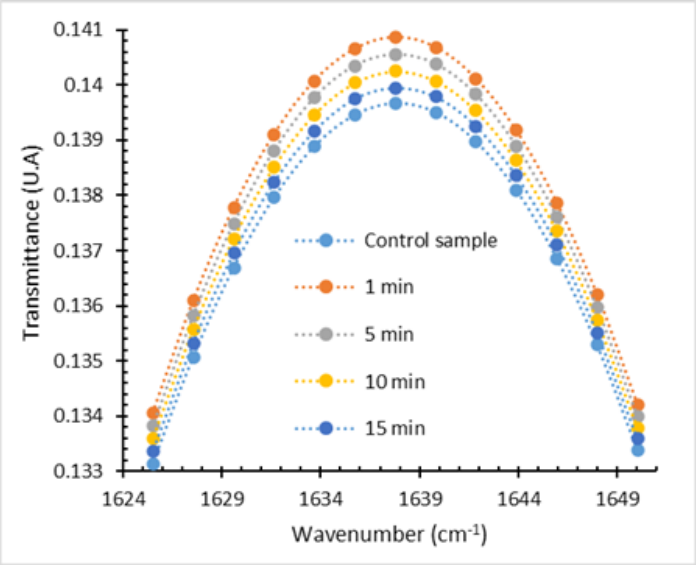


Figure 9. Infrared transmittance of the doped polymer after different plasma exposure times. Range (1620 to 1650 cm^{-1}).

Registro ISSN 2448-8186
DOI:10.19136/Jeeos.a10n3.6695

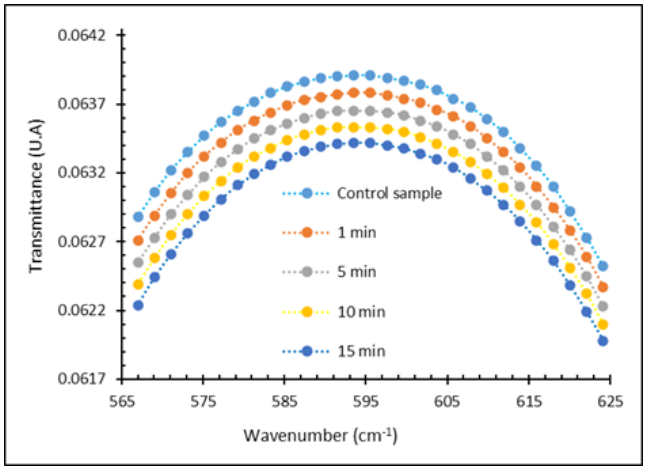


Figure 10. Infrared transmittance of the undoped polymer after different plasma exposure times. Range (565 to 625 cm^{-1}).

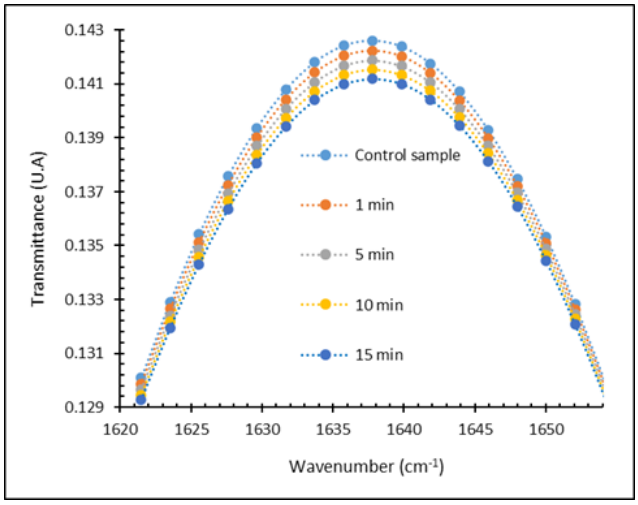


Figure 11. Infrared transmittance of the undoped polymer after different plasma exposure times. Range (1620 to 1650 cm^{-1}).

The dopant and plasma exposure times alter the transmittance intensity of the polymers. F**igures 12 and 13** show the maximum transmittance values for both polymers (doped and undoped) at wavenumbers 593.51 cm^{-1} and 1637.78 cm^{-1}, respectively; these figures illustrate the effects of the dopant and plasma exposure time on transmittance.

In both figures (12 and 13), specific results are observed. The transmittance is always higher for the undoped material than for the doped material at all plasma exposure times. The transmittance value decreases as the plasma exposure time increases. The greatest difference in transmittance value between the two materials is observed for the sample without plasma exposure. The doping material alters the initial transmittance and mitigates the plasma's effect, making the material more resistant to modifications induced by the discharge.

Registro ISSN 2448-8186
DOI:10.19136/Jeeos.a10n3.6695

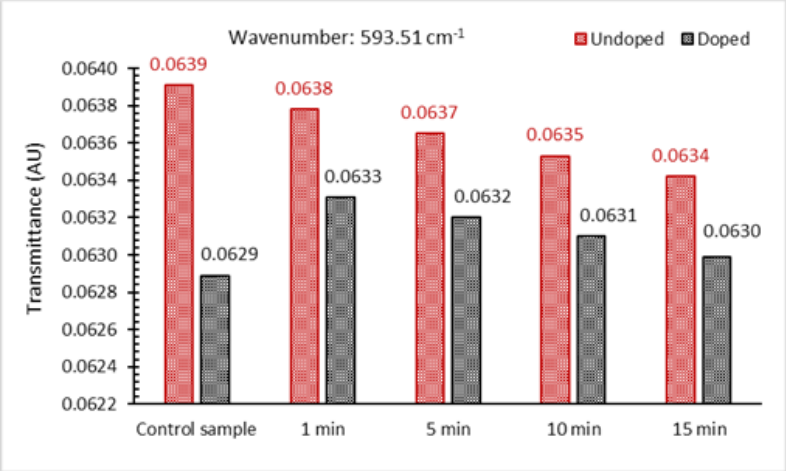


Figure 12. Infrared transmittance values for doped and undoped polymers as a function of plasma exposure time at a specific wavenumber.

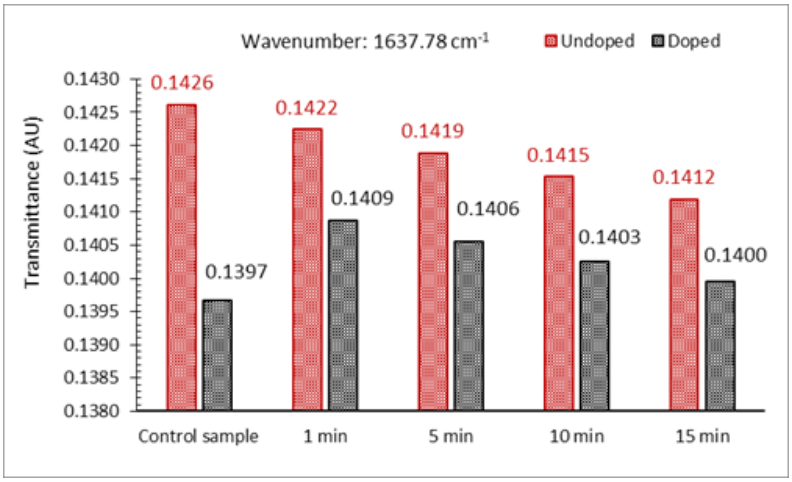


Figure 13. Infrared transmittance values for doped and undoped polymers as a function of plasma exposure time at a specific wavenumber.

DISCUSSION

Air plasma treatments generate reactive species (radicals and ions) that trigger physicochemical processes in the material under study, such as functionalization with oxygenated groups, generation of free radicals via polymer chain cleavage, and removal of contaminants or additives. These modifications can alter roughness, induce variations in crosslinking density, and significantly increase surface energy, thereby enhancing the substrate's wettability [12, 13]. In the specific case of silicone polymers (polydimethylsiloxane, or PDMS), the substitution of methyl groups with reactive oxygen results in a passivation layer rich in glassy Si–O–Si bonds, which modifies the optical transmittance properties [14]. The prevalence of these mechanisms depends on the process kinetics and ionization density, with primary functionalization often transitioning to degradation or crosslinking under higher-power regimes or longer exposure times [15, 16]. The hydrophobic

Registro ISSN 2448-8186
DOI:10.19136/Jeeos.a10n3.6695

recovery phenomenon also persists, partially restoring the initial surface characteristics after treatment [17].

It is observed for both materials (doped and undoped) that the percentage of mass loss increases with increasing plasma exposure time. For short exposure times (5.0 min), the percentage of mass loss is low in both cases, indicating that the processes are superficial and gradually increase. This behavior is explained by the interaction of reactive species in the low-pressure air plasma (ions, radicals, electrons) with the polymer surface, breaking bonds and generating gradual material removal (etching). These physical and chemical effects are highly dependent on the exposure time and the energy supplied to

the ionizing gas (ion bombardment, oxidation, UV radiation) [18]. At the molecular level, the interaction of plasma with PDMS involves cleavage of the siloxane (Si–O) and methyl (CH_3) bonds in the polymer chain, followed by the formation of volatile oxidation products. Furthermore, the presence of silica nanoparticles can locally modify the density of reactive species and the energy distribution on the surface, influencing the surface ablation rate and the etching effect, thus modulating the mass loss between the doped and undoped material as the treatment duration increases [19].

Likewise, the bombardment of energetic plasma ions causes sputtering or microetching, processes that intensify with plasma exposure time and account for the increase in percentage mass loss observed in both data curves [19]. Chemically, oxygen or nitrogen radicals formed by ionizing the air used can interact with the organic matrix of PDMS, forming transient bonds that break, releasing volatile fragments (ethylene glycol, silicon oxides) that are evacuated in the vacuum system, contributing to surface degradation of the materials [2].

The observed trend (percentage mass loss) can also be attributed to structural modifications in the PDMS surface layer, including plasma-induced cross-linking and subsequent microcrack formation and local embrittlement. These processes facilitate the removal of chain segments when the polysiloxane network is sufficiently damaged, especially in the presence of strain concentrators associated with silica nanoparticles, which act as fracture initiators under high plasma species density [2]. Taken together, ionic etching, chemical oxidation, and polymer network modification explain the progressive mass loss, which intensifies with increasing exposure time to low-pressure air plasma, but is less pronounced in the doped material. In other words, the incorporation of dopant particles helps attenuate the material's mass loss.

Regarding the change in hydrophobicity in both materials, it was observed that doping with R812 nanoparticles in the silicone polymer modifies surface hydrophobicity both before and after plasma treatment. This can be deduced from the measured contact angles (angles greater than or equal to 90° indicate a hydrophobic surface).

When the materials are not exposed to plasma (0.0 min), the undoped sample exhibits a larger angle (~111.7°) than the doped sample (~100.2°), suggesting that the dopant initially reduces surface hydrophobicity slightly. This is likely due to the interaction between the dopant nanoparticles and the silicone matrix, which modifies the surface topography and energy without further treatment. The above behavior is consistent with research showing that the incorporation of nanoparticles into a polymer matrix can change surface roughness and energy, varying the contact angle measurement

CC BY NC SA
Registro ISSN 2448-8186
DOI:10.19136/Jeeos.a10n3.6695

depending on the size, dispersion, and surface chemistry of the particles (PDMS with SiO_2 showed angle variation according to nanoparticle content and size) [20].

Plasma treatments generate changes with similar trends, but of varying intensity, in the materials (doped and undoped). In the undoped samples, the plasma causes a very pronounced drop in the contact angle in the first few minutes (from 111.7° to 60.3° at 1.0 min), indicating a strong generation of polar functional groups and an increase in surface energy that makes the surface more hydrophilic, as often occurs with air or oxygen plasma treatments that introduce oxygenated groups and temporarily increase the wettability of some polymers, in this case, PDMS [2].

For the doped samples, although there is also an initial reduction in the angle at the beginning of the treatment (from 100.2° to 83.9° at 1.0 min), this decrease is less extreme than in the undoped samples, and the contact angles of the doped samples recover more rapidly to hydrophobic values (~99.7° at 15 min), approaching their initial state. In general, it is observed that the doping material introduces a certain degree of stability to
the hydrophobicity under plasma treatments.

This behavior can be explained by the fact that silica nanoparticles, especially when dispersed, generate a rougher, more heterogeneous surface topography that favors the recovery or preservation of hydrophobicity after post-plasma surface reorganization. This has been observed in nanocomposites where the nanoparticles increase water repellency by increasing roughness and creating Cassie-Baxter-type wetting states (air trapped between micro/nanostructures) [20].

Plasma treatment has been observed to activate polymer surfaces by introducing polar groups. At long exposure times or after surface reorganization of the polymers, these effects (changes in hydrophobicity) can be mitigated by molecular rearrangement. This effect is favored by the presence of nanometric particles that stabilize surface roughness and reduce the mobility of polymer chains at the interface [2]. Taken together, these results suggest that the SiO_2 dopant attenuates the transformation induced by plasma treatments and promotes faster recovery to the initial state, likely due to a combination of physical (roughness) and chemical (particle-polymer interaction) modifications at the material's surface.

Considering the changes in infrared transmittance of the doped and undoped polymer samples, it can be observed that the values are modified. In both cases, the transmittance generally decreases with increasing plasma exposure time, indicating that the material has undergone chemical and/or structural modifications at its surface or near-surface region, which increase the absorption of infrared radiation. In particular, plasma treatment often induces the formation of new polar functional groups such as –OH, C=O, Si–O–Si, or Si–OH, depending on the polymer and the plasma gas. In the specific case of PDMS, it causes the breaking of $Si–CH_3$ bonds and the formation of Si–O, Si–OH, or oxidized bonds, increasing infrared absorption and thus reducing the recorded transmittance. Oxidation, crosslinking, or surface densification processes also occur, all of which are associated with additional or more intense vibrational modes that absorb energy in the infrared [21, 22]. Furthermore, the reduction in transmittance may be related to an effective increase in the absorption coefficient resulting from the thickening of a plasma-modified surface layer, often described as an oxidized or oxide-like layer. In some cases, the plasma can also generate

Registro ISSN 2448-8186
DOI:10.19136/Jeeos.a10n3.6695

microdefects, roughness, or changes in optical density, thereby increasing scattering and reducing the amount of transmitted radiation.
On the other hand, when PDMS is doped with silica nanoparticles, these SiO_2 particles can serve as additional oxidation and functionalization sites, facilitating surface reactions and generating additional vibrational states that absorb infrared radiation.
This results in a smaller net change in transmittance than in pure PDMS, due to the effects of solid packing and possible saturation of reactive sites [22].

Furthermore, the more moderate decreasing trend in the doped samples indicates that the silica matrix may be promoting a more stable plasma energy distribution and reducing the rate of surface chemical modification, consistent with studies of polymeric composites with fillers that show lower sensitivity to plasma effects but with surface changes detectable by FTIR [22].
Overall, it can be inferred that plasma exposure induces surface oxidation and increases the abundance of polar groups that absorb more efficiently in FTIR, reflected in reductions in transmittance. Likewise, the dopant moderates these changes by acting as an interaction and redistribution site for reactive species, leading to a less pronounced spectral evolution over time.

CONCLUSION

Exposure of the polymer (doped and undoped) to plasma generates progressive modifications that depend on time and the presence of the doping material. The magnitude and kinetics of these changes differ significantly between the doped and undoped samples.
In both experiments, a percentage mass loss associated with etching, oxidation, and ion bombardment mechanisms is observed. The doped polymer consistently exhibits less mass loss at all exposure times. Regarding hydrophobicity, both polymers exhibit an initial decrease in contact angle after plasma exposure, attributed to the incorporation of polar functional groups and the resulting increase in surface energy. However, the doped polymer exhibits a weaker response and a faster recovery to values close to the initial ones as the treatment time increases. Both behaviors (percentage mass loss and change in hydrophobicity) are evidenced by infrared transmittance measurements, confirming that the plasma induces detectable structural and chemical changes in both materials, reflected in a decrease in transmittance with exposure time. Similarly, the doped polymer exhibits a more moderate attenuation of transmittance intensity.
Taken together, these results demonstrate that incorporating the dopant not only modifies the initial properties of the polymer but also reduces changes in response to plasma treatments, attenuating degradation, stabilizing hydrophobicity, and moderating optical changes. From this perspective, the dopant appears to be an effective option for controlling and optimizing the response of plasma-modified polymers. Further analysis is needed to determine the influence of the dopant volume in the polymer on the variables of interest.

CC BY NC SA
Registro ISSN 2448-8186
DOI:10.19136/Jeeos.a10n3.6695

ACKNOWLEDGMENTS

The authors are grateful to Escuela de Estudios Superiores de Xalostoc of Universidad Autónoma del Estado de Morelos, for the facilities provided to carry out this research. This work was funded by PRODEP [DSA/103.5/14/10703].

REFERENCES

[1] R. E. Ñañez Azaña, Modificación superficial de polímeros por tratamientos químicos y físicos, tesis, Pontificia Universidad Católica del Perú, Lima, Perú, 2021. [En línea]. Disponible: https://tesis.pucp.edu.pe/items/ef7f9cd5-3d77-4994-b9fd-1307b9758756

[2] L. B. Neves, I. S. Afonso, G. Nobrega, L. G. Barbosa, R. A. Lima y J. E. Ribeiro, "A review of methods to modify the PDMS surface wettability and their applications," Micromachines, vol. 15, no. 6, p. 670, 2024, doi: 10.3390/mi15060670.

[3] A. Córdoba, E. M. Rivera-Muñoz, R. Velázquez-Castillo y K. Esquivel, "PDMS/TiO_2 and PDMS/SiO_2 nanocomposites: Mechanical properties' evaluation for improved insulating coatings," Nanomaterials, vol. 13, no. 10, p. 1699, 2023, doi: 10.3390/nano13101699.

[4] K. Wei, X. Feng, H. Jiang, C. Li y Y. Hu, "Improvement of heat resistance in silicone rubber by Fe-doped TiO_2 nanoparticles prepared via flame spray pyrolysis," Eur. Polym. J., vol. 200, Art. no. 113139, 2024, doi: 10.1016/j.eurpolymj.2024.113139.

[5] Y. Yu, L. Chen, D. Weng, Y. Hou, Z. Pang, Z. Zhan y J. Wang, "Effect of doping SiO_2 nanoparticles and phenylmethyl silicone oil on the large-scale deicing property of PDMS coatings," ACS Appl. Mater. Interfaces, vol. 14, no. 42, 2022, doi: 10.1021/acsami.2c13650.

[6] S. Gao, H. Zhao, N. Zhang y J. Bai, "Enhanced electromechanical property of silicone elastomer composites containing TiO_2@SiO_2 core-shell nano-architectures," Polymers, vol. 13, no. 3, p. 368, 2021, doi: 10.3390/polym13030368.

[7] T. Dufour, "From basics to frontiers: A comprehensive review of plasma-modified and plasma-synthesized polymer films," Polymers, vol. 15, no. 17, p. 3607, 2023, doi: 10.3390/polym15173607.

[8] M. Bertin, E. M. Leitão, S. Bickerton y C. J. R. Verbeek, "A review of polymer surface modification by cold plasmas toward bulk functionalization," Plasma Process. Polym., vol. 21, no. 2, Art. no. e202300208, 2024, doi: 10.1002/ppap.202300208.

[9] G. Primc, "Surface modification of polyamides by gaseous plasma: Review and scientific challenges," Polymers, vol. 12, no. 12, p. 3020, 2020, doi: 10.3390/polym12123020.

CC BY NC SA

Registro ISSN 2448-8186
DOI:10.19136/Jeeos.a10n3.6695

[10] T. Tsuzuki, K. Baassiri, Z. Mahmoudi, A. S. Perumal, K. Rajendran, G. Montiel Rubies y D. V. Nicolau, "Hydrophobic recovery of PDMS surfaces in contact with hydrophilic entities: Relevance to biomedical devices," Materials, vol. 15, no. 6, p. 2313, 22022, doi 10.3390/ma15062313.

[11] M. Iqbal, D. K. Dinh, Q. Abbas, M. Imran, H. Sattar y A. U. Ahmad, "Controlled surface wettability by plasma polymer surface modification," Surfaces, vol. 2, no. 22, pp.349–371, 2019, doi: 10.3390/surfaces2020026.

[12] J. Tyczkowski, J. Balcerzak, J. Sielski y I. Krawczyk-Kłys, "Effect of carbon black anofiller on adhesion properties of SBS rubber surfaces treated by low-pressure plasma," Polymers, vol. 12, no. 3, p. 616, 22020, doi 10.3390/polym12030616.

[13] J. Tyczkowski, H. Kierzkowska-Pawlak, J. Sielski y I. Krawczyk-Kłys, "Low-temperature plasma modification of styrene-butadiene block copolymer surfaces for improved adhesion: A kinetic approach," Polymers, vol. 12, no. 4, p. 935, 2020, doi: 10.3390/polym12040935.

[14] M. Bodas, J.-Y. Rauch y C. Khan-Malek, "Surface modification and aging studies of addition-curing silicone rubbers by oxygen plasma," Eur. Polym. J., vol. 44, no. 7, pp. 2130–2139, 2008, doi: 10.1016/j.eurpolymj.2008.04.012.

[15] M. A. Martínez, J. Abenojar y D. García-Pozuelo, "Effect of plasma treatment on coating adhesion and tensile strength in uncoated and coated rubber under aging," Materials, vol. 18, no. 2, p. 427, 2025, doi: 10.3390/ma18020427.

[16] C. Bai, Z. Gong, L. An, L. Qiang, J. Zhang, G. Yushkov et al., "Adhesion and friction performance of DLC/rubber: The influence of plasma pretreatment," Friction, vol. 9, no. 3, pp. 627–641, 2021, doi: 10.1007/s40544-020-0436-6.

[17] S. Ďurišová, M. Pajtášová, D. Ondrušová, R. Janík, Z. Mičicová, A. Dubec et al., "Effect of low-temperature plasma treatment on rubber properties," Polimery, vol. 69, no. 4, 2024, doi: 10.14314/polimery.2024.4.5.

[18] T. Junkar y A. Vesel, "Low-pressure non-equilibrium plasma technologies: Scientific background and technological challenges," Rev. Mod. Plasma Phys., 2025, doi: 10.1007/s41614-025-00201-x.

[19] L. T. Phan, S. M. Yoon y M.-W. Moon, "Plasma-based nanostructuring of polymers: A review," Polymers, vol. 9, no. 9, p. 417, 2017, doi: 10.3390/polym9090417.

[20] J. Lu, M. Mei y C. Huang, "Influence of silicon dioxide nanoparticles on hydrophobicity and transparency of polydimethylsiloxane coatings hybridized with silicon dioxide nanoparticles," Thin Solid Films, vol. 828, Art. no. 140800, 2025, doi: 10.1016/j.tsf.2025.140800.

Registro ISSN 2448-8186
DOI:10.19136/Jeeos.a10n3.6695

[21] K. Krawczyk, A. Jankowska, M. Młotek, B. Ulejczyk, T. Kobiela y K. Ławniczak-Jabłońska, "Surface modification of silicone by dielectric barrier discharge plasma," Materials, vol. 16, no. 8, p. 2973, 2023, doi: 10.3390/ma16082973.

[22] A. Tshikovhi, S. B. Mishra y A. K. Mishra, "Effect of silica content in a bio-polymeric blended nanocomposite for efficient adsorption of mercury in basic aqueous solution," Fibers Polym., vol. 26, pp. 521–535, 2025, doi: 10.1007/s12221-025-00854-y.

Registro ISSN 2448-8186
DOI:10.19136/Jeeos.a10n3.6695