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PREPARATION AND CHARACTERIZATION OF PHOSPHORUS YTTRIUM GLASS MICROSPHERES FOR RADIOTHERAPY APPLICATIONS

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The paper examines the novel method of embedding phosphorus particles into the matrix of yttrium aluminum silicate microspheres. Yttrium phosphorus glass microspheres around 20 µm in size when aqueous solution of YCl_3 and $AlCl_3$ was added in to TEOS, (phosphoric acid was used to catalyze the hydrolysis and condensation of tetraethyl orthosilicate) and pumped in to stirred silicon oil were obtained. The shapes of particles produced by this method are regular and very close to spheres. The amorphous structure of PO_4^{3-} and Si-O bands, spherical shapes , composition and element distribution are examined through the use of X-ray Diffraction (XRD), Fourier-transform Infrared Spectroscopy (FTIR), Scanning Electron Microscopy (SEM), X-Ray Fluorescence Spectroscopy (XRF), the Carbon / Sulfur Determinator and SEM/EDS Mapping and Line scan Analysis, respectively. The results show that the silicone oil spherodization method may be effective in the production of yttrium phosphorus glass microspheres.

***Keywords**: yttrium phosphorus glass microspheres, tetraethyl orthosilicate*

Radiotherapy is one of the most effective treatments of cancers. It has been reported that glass microspheres 20-30 µm in diameter of $17Y_2O_3$-$19Al_2O_3$-$64SiO_2$ (mol %) composition are useful for in situ irradiation of cancers [1-15]. Yttrium-89 in the glass can be activated to b-emitter, ^{90}Y, with a half life of 64.1 h by neutron bombardment. Other elements constituting the glass are not activated by the neutron bombardment.

Similarly to the isotope 89Y, the isotope 31P can be transmuted to 32P which is β-emitter with a half-life of 14.3 days and can be more effective to cancer treatment when compared to 90Y [1]. However, 90Y may undergo substantial decay even before the cancer treatment, because of its short half-life of 64.1 h. Phosphorus-31, with 100% natural abundance can be activated to become a β-emitter, 32P, with a longer half-life of 14.3 d via neutron bombardment. Moreover, the biological effectiveness of 32P is estimated to be 4 times as large as that of 90Y [2-8].

P^+ ions implanted in Y_2O_3–Al_2O_3–SiO_2 glasses, show promising results [2-7]. However, phosphorus can be a problem in some types of glasses because it usually plays an important role in the nucleation of crystalline phases, as observed for some silicate glasses [1].

In this paper we focus on the new methods for embedding of phosphors element into the matrix of microspheres by sol gel method. The motivation behind this work is the spherodaization of phosphorus yttrium aluminum silicate micro particles without high temperatures and embedding of phosphors element into the matrix of microspheres without using ion implantation. With XRD, the stability of crystalline phases after heat treatment is investigated. With Fourier-transform infrared spectroscopy **(**FTIR), the absorption bands of the mineral phase are studied. XRF analysis was performed to determine the elements. The Carbon/Sulfur determinator was used to identify carbon. SEM/EDS Mapping and Line Scan Analysis were used to determine the element distribution into the cross section of microsphere.

EXPERIMENTAL PROCEDURES

The yttrium chloride (YCl_3) is obtained by reaction of yttrium oxide and hydrochloride acid. SiO_2 colloids were produced by adding tetra ethyl orthosilicate (TEOS) into water when stirring at room temperature. The molar composition of TEOS: H_2O: H_3PO_4 was 1: 1: 0.5, which is described as the optimum composition for obtaining Yttrium Aluminum Silicate sol. The Y and Al ions were incorporated in the SiO_2 by replacing the water by an aqueous solution of YCl_3 and $AlCl_3$, respectively.

Prepared solution was loaded into a syringe and pumped through a 0.4 mm diameter nozzle into silicone oil (Shenzhen Hong Ye Jie Technology Co., Ltd.) under magnetic stirring (500 rpm). The silicone oil is thermo-stated at 75-80 ºC. The solution droplets were therefore converted into solid gel spheres into the silicone oil after 30 minutes.

Microspheres were separated from the silicone oil by precipitation and washed with 30 ml of petroleum ether (This process was repeated at least three times) and then washed with 10 ml of diethyl ether to remove the trace of silicone oil from the surface of particles. Finally, the obtained microspheres are washed with 100mL of water.

To remove the remind acids and other additives, microspheres were heated at 500 ºC for 3 h in a furnace. The temperature rise up to 500˚C by 5˚C/min after 3 h at 500˚C it reduces by 10˚C/min.

RESULTS

X-ray diffraction analysis (XRD)

For determination of crystallization of samples, those are analyzed by X-ray diffraction system after heat treatment of samples at 500 ˚C. In figure 1 the XRD patterns after heat treatment at 500˚C for 3 h is shown.

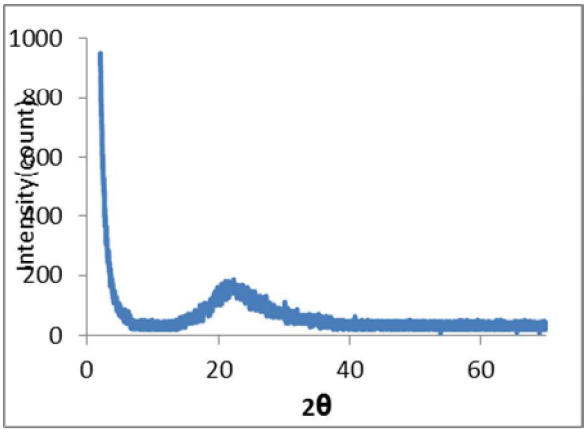

Fig.1. XRD patterns of yttrium phosphorus glass, sample after heat treatment at 500 ˚C for 3 h.

Fourier-transform infrared spectroscopy (FTIR)

For FTIR spectra 2 mg of sample added with 300 mg of spectral grade potassium bromide (KBr). The mixtures were ground and pressed to form a transparent disk. To scan the samples, the transmittance technique is used. Figure 2 shows the FTIR spectra in the range of 350-4000 cm^{-1} after heat treatment at 500 ˚C for 3 h.

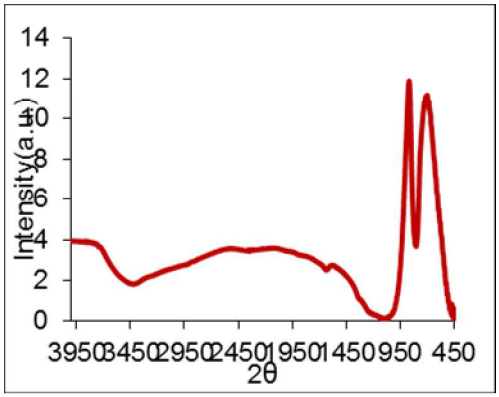

Fig.2. The FTIR spectra for microspheres after heat treatment at 500 ˚C for 3 h.

This figure clearly shows that two observed bands are visible around in the 800 cm^{-1} and 1100 cm^{-1} wave numbers.

Scanning electron microscopy (SEM)

About 1 mg of dry powder is placed on a 1 Cm^2 glass slide and two droplets of petroleum ether on it to distribute powders evenly on the surface of glass slide. After drying the samples were sputter-coated with Au–Pd for SEM work to reduce electrostatic charging.

The SEM pictures of samples prepared by silicon oil method are shown in figure3.

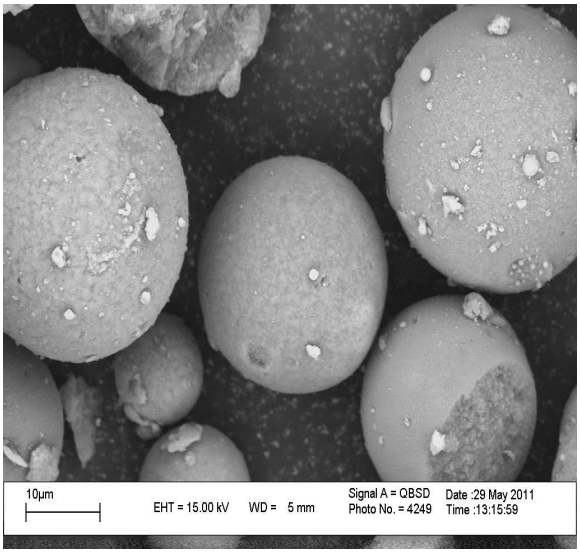

Fig.3. The SEM micrograph of glass particles with using silicon oil method to spherodization.

These figures shows the micrographs of regular spherical particles that prepared by sol gel method and using silicon oil to spherodization after annealing at 500 ˚C for 3 h.

SEM/EDS Mapping Analysis

Microsphere samples are primarily mounted to thus ease in manipulation operations in the course of preparation. These powders are mounted in polycarbonate disc 30 mm in diameter and 5 mm long. Compression molding techniques are used to produce hard mounts in a minimum amount of time. Temperature and pressure are constant factors in the design of the mounting press.

The mount is inserted into the polishing tool and tightly pressed by fingers and Movement 20 times on Abrasive paper in a straight line across the abrading surface toward or away from the operator. This process is occurred with water by using 1000, 1500, 2000, 2500 and 3000 grit paper, respectively.

Chemical analyzing

The sol composition and achieved microspheres density listed in table.

Elements in Az1 and Az2 samples

Amount (%) / Samples	Al_2O_3	SiO_2	P_2O_5	Y_2O_3	La & Lu	C
Az 1	10.4	29.8	14.4	45.4	<1	0.04
Az 2	-	17.2	18.4	64.3	<1	0.04

The samples marked as Az 1 and Az 2. (free Al) Semi quantitative analysis was performed on samples according to ASTM C 982-03. XRF analysis was performed to determine the elements, while carbon / Sulfur determinator was used to identify carbon. Table 1 shows the elements in Az 1 and Az 2 (free Al) samples microspheres.

DISCUSSION

X-ray diffraction analysis

The figure 1 shows the XRD patterns of samples after heat treatment at 500 ˚C. From this it follows that the samples are not crystalline. The figure 1 enables us to conclude that these glasses are stable and bear no traces of crystalline phases after heat treatment at 500 ˚C for 3 h. This figure also confirms that the yttrium phosphorus aluminum silicate oxides exist in their amorphous state in these glass microspheres composite up to 500 ˚C. The nucleation of crystalline phases is undesirable because it can induce stresses in the glass structure and interfere in the performance of the microspheres by creating cracks and other defects [1].

Fourier-transform infrared spectroscopy (FTIR)

The spectrum for the microspheres (figure 2) clearly shows that the absorption bands of the mineral phase are visible within the 800 and 1100 cm^{-1} region. The peak observed in the 800 cm^{-1} can be attributed to the absorption bond of the Si-O-Si [3, 16-21]. And the peak observed in the 1100 cm^{-1} can be attributed to the vibration mode of the Si-O-Si bond [22] or stretching vibration of the PO_4^{3-} group [23-25]. Other combinations like Y-O, Y-Si, and Al-O are likely impossible because they would produce short wavelength peaks or they are outside of the measured range.

Scanning electron microscopy (SEM)

Figure 3 shows glass particles with regular spherical shapes. These figures confirm that the silicon oil method is the novel way for the production of closed spherical particles.

With no high temperatures applied, this method is an appropriate way for the production of non-metallic glass microspheres in case where oxides have a low temperature boiling point such as phosphor glass microspheres.

Figure 3 shows that the most of the particles obtained by this method are around 20-50 μm in diameter. Hence, the procedure to obtain this material is appropriate.

SEM/EDS Mapping Analysis

The topographical analysis of microspheres shows that the Y, P, Si, O, and Al elements distribute approximately into the microspheres and the distribution of elements into the samples is homogenized figures 4, 5.

Chemical analyzing

Table 1 shows that 14.4% and 18.4% of samples Az 1 and Az 2 respectively are formed by P_2O_5. The advantage of this method as compared with other methods [2-7] is that no P^+ ion implantatio

CONCLUSION

Phosphor elements in the matrix of yttrium glass microspheres were obtained in the aqueous solution of YCl_3, $AlCl_3$ and phosphoric acid was added into TEOS and pumped into stirred silicon oil. The shapes of particles produced by this method are regular and very close to spheres. The results show that silicone oil spherodization method may be applied for the production of yttrium phosphate glass microspheres.

Without applying high temperatures, it's a suitable way for the production of non-metallic glass microspheres when adjusted fir the fact that oxides have a low temperature boiling point and are not resistant to crystallization at low temperatures such as phosphor glass microspheres. The superiority of this method rather than other methods is that no P^+ ion implantation [2-7] and high temperatures [1, 4, 9-10, 16] are required.

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FOSFOR İTTRİUM ŞÜŞƏ MİKROKÜRƏLƏRİN HAZIRLANMASI, XARAKTERİSTİKASI VƏ RADİOTERAPİYADA TƏTBİQİ

M.R.Qəhrəmani

Məqalədə fosfor hissəciklərinin ittrium-alüminium silikat mikrokürələrin matrisinə daxil edilməsinin yeni bir üsulu haqqında məlumat verilir. YCl_3 və $AlCl_3$-un sulu məhlulları TEOS-a (fosfor turşusu tetraetilortosilikatın hidroliz və kondensasiyasının katalizi üçün istifadə edilmişdir) əlavə edilməklə və qarışdırılan silikon yağına vurulmaqla ölçüsü 20 mkm olan ittrium fosfat şüşə mikrokürələr alınmışdır. Alınan hissəciklərin forması müntəzəmdir və kürəyə çox yaxındır. Amorf quruluş, PO_4^{-3} və Si-O rabitələri, sferik formalar, tərkib və elementlərin paylanması müvafiq olaraq rentgen diffraksiyası (RD), İQ-Furye spektroskopiya, skanerləyici elektron mikroskopiya (SEM), rentgen flüoresent spektroskopiyası (RFS), karbon/kükürd təyinedicisi və xətti analiz (SEM/EDS) metodları ilə tədqiq edilmişdir. Nəticələr göstərir ki, silikon yağının sferoidizasiya metodu ittrium fosfat şüşə mikrokürələrin istehsalı üçün çox əlverişli üsul ola bilər.

Açar sözlər: *ittrium fosfat şüşə mikrokürələr, tetraetilortosilikat*

ПОДГОТОВКА И ХАРАКТЕРИСТИКА ИТТРИЙ-ФОСФОРНЫХ СТЕКЛЯННЫХ МИКРОСФЕР ДЛЯ ПРИМЕНЕНИЯ В РАДИОТЕРАПИИ

М.Р.Кахрамани

В работе сообщается о новом методе введения частиц фосфора в матрицу иттрий-алюминиевых силикатных микросфер. Иттрий-фосфорные стеклянные микросферы размером около 20 мкм получали добавлением водных растворов YCl_3 и $AlCl_3$ в ТЭОС (фосфорная кислота была использована для катализа гидролиза и конденсации тетраэтилортосиликата) и закачиванием полученной смеси в перемешивающееся силиконовое масло. Формы частиц, полученных с помощью этого метода, регулярные и очень близки к сфере. Аморфная структура, PO_4^{3-} и Si-O связи, сферические формы, состав и распределение элементов, соответственно исследованы с помощью рентгеновской дифракции, ИК-Фурье спектроскопии, сканирующей электронной микроскопии (SEM), рентгеновской флуоресцентной спектроскопии, углерод/сера определителя и анализа строчной развертки (SEM/EDS). Результаты показывают, что метод сфероидизации силиконового масла может быть очень подходящим способом для производства иттрий-фосфорных стеклянных микросфер.

Ключевые слова: *иттрий-фосфорные стеклянные микросферы, тетраэтилортосиликат.*

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