

Separation of Some Drugs by HPLC using New Cross linked Co-polymer of (Triethyl amine glyceryl maleate)

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Abstract

A rigid, easy grinded and highly stable cross linked poly (triethyl amine glyceryl malate) was synthesized by condensation polymerization of a mixture of triethanol amine and glycerol with maleic anhydride. The synthesized polymer was used as a stationary phase for HPLC to analyze some drugs like furosemide, atenolol, and amiloride. The study investigate the effect of phosphate buffer concentration and pH on the analysis of the drugs. The practical pH for the drug separation was found to be 8, whereas, the eluent was 20% phosphate buffer and 80% methanol giving good analysis results using isocratic elution. The retention times for furosemide, atenolol, and amiloride were 4.64min, 7.05min, and 9.16min, respectively. The separation was improved by using elution gradient (0-20)% phosphate buffer in methanol, flow rate 1ml/min and wavelength 233nm. High recoveries were obtained for the drugs, in the range from 95-98%, by using the new column. The obtained results were compared with commercial column ODS-C18 and the method of analysis was extended for determination of the drugs in pharmaceutical tablets as well as in serum samples.

Introduction

Stationary phase materials are based on particles of a cross linked organic polymer were introduced as packing in column liquid chromatography since the sixties of the last century⁽¹⁾. Typical materials of this kind of stationary phase were polystyrene divinyl benzene copolymer (PS-DVB) and modified PS-DVB materials⁽²⁾. However, many workers have synthesized polymer or modified silica gel with polymers for chromatography techniques to separate different type of chemicals⁽³⁻⁷⁾.

Kwang-Pill Lee and co-workers have prepared cyclodextrin (CD) polymer from the reaction of cyclodextrin with hexamethylene diisocyanate. The polymer was conducted as a stationary phase for backing the HPLC column and used to separate phenol isomers (o, m, and p-nitrophenol)⁽⁸⁾.

A temperature-responsive modified poly(N-isopropyl acryl amide) surface was investigated for HPLC with aqueous media as a mobile phase⁽⁹⁻¹¹⁾.

This polymer was found to be useful for separation of steroids and amino acids and expected to applied in the pharmaceutical and biomedical fields.

Yokoyama et. al. have utilized new developed macro porous polystyrene-divinylbenzene copolymer for separation of amino acids.⁽¹²⁾

On the other hand, separation of medicines like furosemide, atenolol and amiloride has been widely investigated by HPLC techniques.

Ronald with his co-workers⁽¹³⁾ have determined furosemide in plasma and urine by reverse-phase HPLC and fluorescence detection using Zorbax column (SB-C816), while Sekikawa has determined furosemide in blood by using Shim-pack CLC-ODS column⁽¹⁴⁾.

Moreover, Luis and his workers have developed an HPLC for determination of atenolol in human plasma⁽¹⁵⁾.

The concentration were analyzed by reverse phase liquid chromatography with fluorescence detection at 300nm wavelength. Other workers have determined atenolol by HPLC in pharmaceutical formulation^(16, 17).

The determination was carried out on a reversed phase C18 column using 0.1% ortho phosphoric acid pH=3 acetonitrile 20:80 at a flow rate of 1.0ml/min with U.V-detection at 238nm.

The present study was undertaken to evaluate the efficiency of using newly prepared copolymer as

stationary phase for HPLC to separate some medicines like furosemide, atenolol and amiloride. Isocratic and gradient mobiles were applied for separation as well as the properties of the mobile was studied. The investigation was extended to compare the results obtained from the new column with the commercial column type ODS-C18.

Experimental

Equipments

High performance liquid chromatography type shimadzu(Japan) which consisted of a system controller model SCL-10AVP, A DEGASSER MODELdgu-12A, two liquid delivery pumps model LC-8AVP, UV-Visible detector modelSPD-10AVP, and injector model SIL-10A, equipped with 20ul sample loop were used. The HPLC system has been interfaced with computer via a Shimadzu class-VP5 chromatography data system program supplied by the manufacturer; Epson LQ-300 printer model P852A.

Sonicator Sonerex model Super PK 103H Mandolin (Germany). Combination glass electrode was used to measure the pH of polymer solution (Germany). Two blank stainless steel columns, dimensions 25×0.4cm (i.d.) were obtained locally.

Preparation of the (triethylamine glyceryl maleate) copolymer⁽¹⁸⁾:

A mixture of triethanol amine (7.45gm, 0.05mole) and glycerol (4.61gm, 0.05mole) were placed in a 100ml round-bottom flask equipped with a thermometer and stirrer. The mixture was stirred for 15min, then maleic anhydride (14.7gm, 0.15mole) was added to the mixture and the temperature raised gradually to 160C by sand bath. The reaction mixture was heated at this temperature for 3hrs causing an increase in viscosity of the solution and a crystalline polymer was formed. The final product was washed with warm water and methanol for several times, then dried in vacuum oven at 50C over night.

Preparation of Standard Drug Solutions

A stock solution of 50ppm of standard drugs were prepared by dissolving 5mg of furosemide in 0.1NaOH then diluted to 100ml with distilled water, or by dissolving 5mg of the furosemide in methanol and then diluted to 100ml with distilled water. The same procedure for the preparation of stock solution for

atenolol and amiloride was followed. Other standard solutions were prepared by subsequent dilution of the stock solutions.

The solvent used to prepare these solutions before injection into HPLC was the buffer that was usually used as the mobile phase employed for their separation.

Results and Discussion

The synthesis of the cross linked co-polymer, used as stationary phase in this work, was done via condensation polymerization of a mixture of triethanol amine and glycerol with maleic anhydride which produces a hard, and rigid product. The degree of cross-linking has been measured using polar, moderately polar and non polar solvents that are usually used in HPLC such as (water, acetone, acetonitrile and hexane). The high degree of cross linking of the copolymer prevent the solvation process and for this reason it was difficult to determine the molecular weight and the degree of polymerization.

The x-ray diffraction results showed that the polymer have different crystalline forms. Swelling test for the prepared polymeric stationary phase was performed according to the ASTM procedure which indicate that the swelling ranged from 1%-4% as theoretically expected. The solubility has been examined using different solvents such as acetonitrile, benzene, chloroform, dioxane, DMF, DMSO, hexane methanol and water. It is found that the polymer was insoluble in all the above solvents. These results were attributed to the high cross-linking of the polymer. However, full detail of polymer characterization has been described elsewhere⁽¹⁸⁾.

Column packing was done following down-flow packing method⁽¹⁸⁾ of the homogenized slurry mixture of the copolymer powder in 100ml of acetonitrile. pH and phosphate buffer concentration effect on these drugs were examined and the results show that no drugs can be detected at pH less than 6 or higher than 9.

The capacity factor K' using methanol and phosphate buffer as eluent at different pH were calculated as shown in Fig (1).

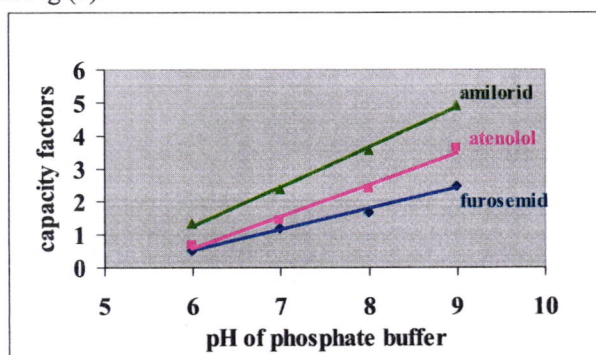


Figure (1) Plot of Capacity factor, versus pH, using triethanolamine-glycerol-maleate column, flow 1 ml / min, detection wavelength 233nm and 10 ppm furosemide, atenolol and amiloride sample

The separation factor (α) values for furosemide, atenolol, and amiloride were in the following ranges (1.25-1.28), (1.22-1.24), (1.09-1.11), and (1.19-1.27) at pH6, 7, 8, and 9, respectively. These variation in capacity factors and

separation factors of these analytes may indicate that the pH=8 is the practical buffer that can be used for separation. The variation of the capacity factor and separation factor for these medicines with different percentage of phosphate buffer (percentage in methanol) ranged from 5%-20% are listed in table(1).The results exhibits a good competitive interaction of these drugs with the stationary phase and the selected mobile phase of methanol at 20% phosphate buffer Fig.(2).

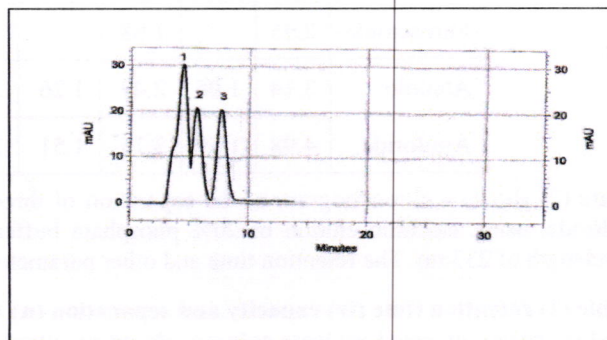


Figure (2) chromatogram of standard mixture of 0.2 amiloride (1), 0.1 ppm of column. Furosemide(2) and 0.5 ppm of atenolol (3), using triethanolamine - glycerol-maleate. Eluent 20%phosphate buffer - 80%MeOH, flow rate 1ml/min, and detection wavelength 233nm.

The order of interaction of the drugs with the stationary phase due to the retention time was in the following order;

Amiloride > atenolol > furosemide

The interaction of these drugs depends on the hydrogen bonding between N-H group of the drug and O-H group of the copolymer.

The separation of these drugs in mixture was improved by using gradient elution programming as shown in Fig.(3).

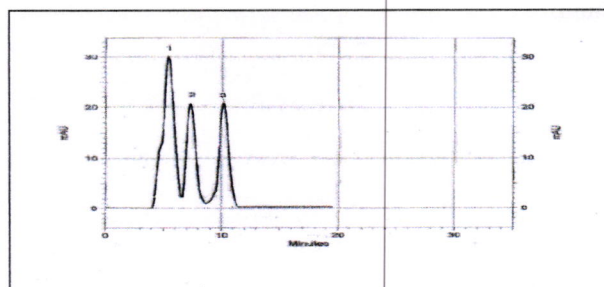


Figure (3) chromatogram of Separation of standard mixture of 0.2 ppm furosemide (1), ppm of atenolol (2) and 0.5ppm of amiloride (3), using triethanolamine - glycerol - maleate column. Eluent gradient (0-20) %phosphate buffer in MeOH, flow rate 1ml/min at wavelength 233nm.

The new column performance was compared with commercial column ODS-C18.

Table (1) Capacity K' and separation α factor variation with changing of composition of mobile phase for drugs using triethyl amine-glyceryl-maleate column.

compounds	Percentage of phosphate buffer in mobile phase									
	5%(0.01m) of buffer		10%(0.02m) of buffer		15%(0.04m) of buffer		20%(0.05m) of buffer		25%(0.06m) of buffer	
	K'	α	K'	α	K'	α	K'	α	K'	α
Furosemide	2.95		1.98		1.86		1.52		--	--
Atenolo	3.14	1.06	2.49	1.26	2.15	1.16	1.85	1.22	--	--
Amiloride	4.98	1.59	3.75	1.51	2.74	1.28	2.34	1.27	--	--

Figure (2) shows a chromatogram of the separation of three drugs; 0.2ppm furosemide, 0.1ppm atenolol and 0.5ppm amiloride, using isocratic elution of 20% phosphate buffer and 80% methanol at pH=8, flow rate of 1ml/min and wavelength of 233nm. The retention time and other parameters for separation of the drugs are listed in table (2).

Table (2) retention time (tr) capacity and separation (α) factors, resolution and peak asymmetry for drugs using triethyl amine-glyceryl-maleate column, eluent gradient 20% phosphate buffer-80% MeOH, flow rate 1ml/min and detection wavelength 233nm

compounds	Retention Time (tr)	Capacity factor	Separation factor α	Resolution	Peak Asymmetry
Furosemide	4.65	1.52	----	----	1.14
Atenolol	7.05	1.85	1.22	1.22	0.99
Amiloride	9.16	2.13	1.27	1.45	1.02

Hence, amiloride, atenolol and furosemide samples were chromatogramed on C-18 with flow rate of 0.8ml/min. The mobile phase for elution of the drugs was as follows: amiloride; a mixture of 60% phosphate buffer and 40% methanol at pH 2.6 gave retention time of 3.35 min, for furosemide was 46% methanol and 54% phosphate buffer at pH 2.0 gave retention time of 23.35 min. While for atenolol the mobile was 65% methanol-5% THF-30% buffer phosphate at pH 2.6, the retention time was 7.55min.

The separation of the mixture cannot be performed because of the different in the composition of the mobile phases. Therefore, ODS-C18 was a very good column for the determination of each drug individually.

Quantitative analysis was studied from the construction of calibration curves for the drugs. The linear calibration curves for atenolol, amiloride and furosemide are shown in Fig (4).

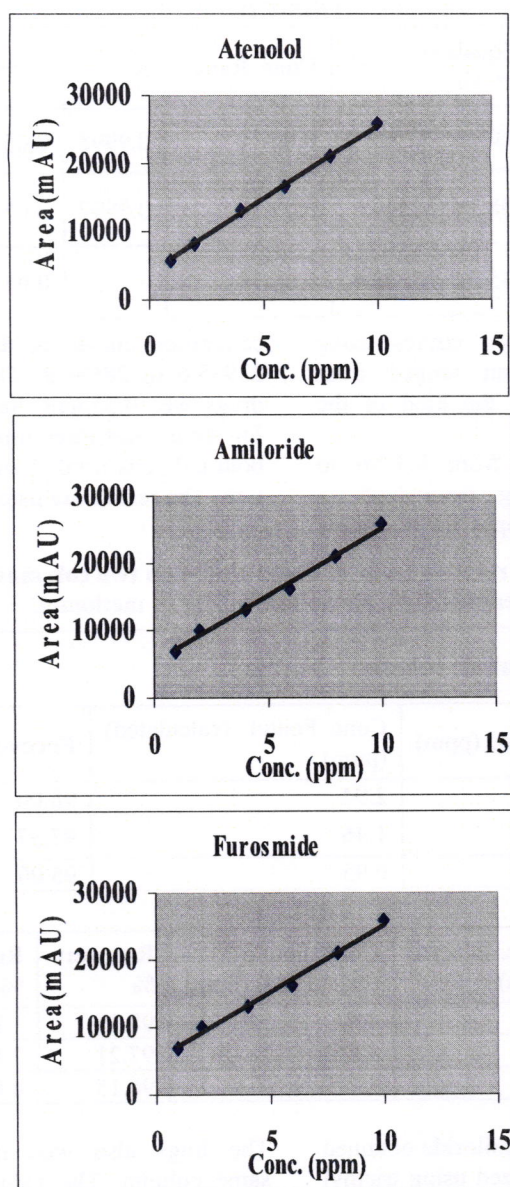


Figure (4) calibration curves for the drugs using triethanolamine –glycerol-maleate column. Eluent gradient (0-20) %phosphate buffer in methanol

The linear equation and concentration range with the detection limit using the triethyl glyceryl maleate polymer and ODS-C18 columns, eluent gradient (0-20)%phosphate buffer in methanol flow rate of 1ml/min at wavelength 233nm are listed in table (3).

Table (3) Linear equation, correlation coefficient and detection limits for the drugs using two types of columns

Triethyl amine-glyceryl-maleate column				
Compounds	Linear Equation $Y^* = mx^* + b$	Conc. Range	R	Detection Limit (ppm)
Furosemide	$Y = 56221.6x - 35273.4$	0.1-10	0.9998	0.1
Atenolol	$Y = 58962.1x - 37301.6$	0.05-10	0.9997	0.05
Amiloride	$Y = 59495.9x - 38576.2$	0.05-10	0.9998	0.05

ODS-C18

Compounds	Linear Equation $Y^* = mx^* + b$	Conc. Range	R	Detection time(ppm)
Furosemide	$Y = 28636.9x - 22922.2$	0.05-10	0.9998	0.05
Atenolol	$Y = 26758.1x - 20244.6$	0.05-10	0.9997	0.05
Amiloride	$Y = 23935.6x - 18138.4$	0.05-10		0.05

The slopes for the linear calibration curves using triethanolamine-glycerol-maleate column ranged from 56221.6 to 59495.9 depending upon the kind of the drugs.

The correlation coefficients ranged from 0.9996 to 0.9998 with detection limit ranging from 0.05 to 0.10ppm. While for ODS-C18, the slopes for the linear

calibration curves of the analyzed drugs ranged from 23935.6 to 28636.9. The detection limit for the three drugs was 0.05ppm. Standardized solutions were injected for the at least three times under the same condition for both columns triethyl amine-glyceryl-maleate and ODS-C18. The results are listed in table (4).

Table (4) Recovery and percentage relative error of drugs eluted on two columns for the drugs using gradient eluent (0-20)% phosphate buffer in methanol.

Triethyl amine-glyceryl-maleate column				
Drugs	Conc. Injected (ppm)	Conc. Found (calculated) (ppm)	Recovery %	Relative Error %
Furosemide	3.00	2.94	98.00	2.00
Atenolol	1.50	1.46	97.37	2.67
Amiloride	1.00	0.95	95.00	5.00

ODS-C18

Drugs	Conc. Injected (ppm)	Conc. Found (calculated) (ppm)	Recovery %	Relative Error %
Furosemide	5.00	4.91	98.25	1.80
Atenolol	5.00	4.86	97.21	2.80
Amiloride	5.00	4.77	96.15	4.60

Solutions of furosemide, atenolol and amiloride obtained from three different tablets were analyzed using triethyl amine-glyceryl-maleate column, mobile phase was gradient (0-20)% phosphate buffer in methanol, flow rate 1ml/min at wavelength 233nm. The %RSD are; 0.845%, 0.841% and 0.809% for furosemide, atenolol and amiloride, respectively are listed in table (5).

The drugs, also, were determined in serum under the same column. The value for furosemide ranged from 16.77- 17.86 after two hours, while for atenolol ranged from 45.44-46.87 after two hours and for amiloride ranged from 4.23-4.41 after two hours.

Table 5 Analysis of amiloride(5mg), furosemide (20mg), and atenolol (50mg) in tablets using triethyl amine-glyceryl-maleate column.

companies		Amiloride	Furosemide	Atenalol
Samara	Wt.(mg) injected	5.00	20.00	50.00
	Wt.(mg) calculated	4.98	19.95	49.97
	Recovery %	99.25	99.77	99.42
India	Wt.(mg) injected	5.00	20.00	50.00
	Wt.(mg) calculated	4.484	17.98	48.12
	Recovery %	96.24	88.28	95.64
Egypt	Wt.(m injected g)	5.00	20.00	50.00
	Wt.(mg) calculated	4.91	18.84	48.53
	Recovery %	98.16	94.23	97.44

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Optical Properties Of Pure Tin Oxide (SnO₂) Thin Film and Doped with (Cu) Prepared By Chemical Spray Pyrolysis Technique

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Abstract

In this work the effect of Cu impurities on the optical properties of SnO₂ thin films studied which prepared by chemical spray pyrolysis on glass substrates at temperature 773 K, the molarity of the solution was (0.1M)
To obtain the optical parameters, the absorption and transmittance spectra were recorded in the wave length range (300-720) nm.

The calculated energy gap for direct transitions is 3.8 eV for pure sample and 4 eV for doped one.

Also the absorption coefficient, reflectivity, refraction index, extinction coefficient, real and imaginary parts of dielectric constants as a function of photon energies for pure and doped samples were calculated.

Introduction

It is not understatement to say that thin-film advance techniques have, in the past three decades, fundamentally changed both condensed matter physics and everyday life. Well established thin-film technologies are used to grow the integrated circuits in our computers, cell phones, and palm pilots, while novel effects in thin films continue to be discovered and explored by both solid-state physicists and optical physicists. Many of the techniques used to grow thin films are related, and many involve physics and technology of marvelous subtlety[1].

Stannic oxide (SnO₂)

In 1942 McMasters succeed for the first time in preparing a transparent conductive tin oxide film. A substance with white color, have a molecular weight of (150.69 g/mol), density of (6.95 g/cm³), melting point (1630 °C), and boiling point (1900 °C). Stannic oxide in its pure form is an n-type wide band gap semiconductor . Its electrical conduction results from the existence of point defects which act as donor or acceptors. The property of SnO₂ makes the material useful for many applications; therefore increasing attention is being paid to studies this oxide especially on the method of operation, and its electrical and optical properties.[2]

The lattice structure is illustrated in fig (1).

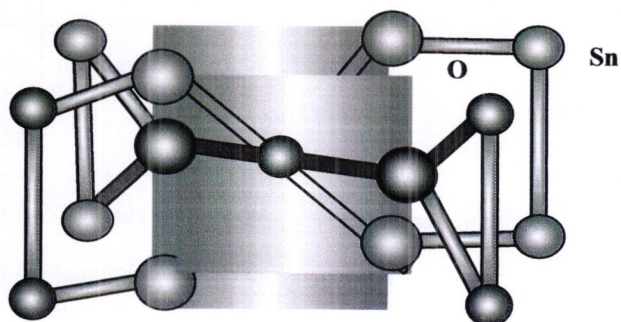


Fig (1):Lattice structure of SnO₂ [3]

Copper

Copper is a reddish metal with a face-centered cubic crystalline structure. It reflects red and orange light and absorbs other frequencies in the visible spectrum, due to its band structure, so it as a nice reddish colour. It is malleable, ductile, and an extremely good conductor of both heat and electricity. It is softer than iron but harder than zinc and can be polished to a bright finish. It is found in group Ib of the periodic table, together with silver and gold. Copper has low chemical reactivity. In moist air it slowly forms a greenish surface film called patina; this coating protects the metal from further attack, table (1) show some physical and chemical copper properties .[4]

Table (1)show some physical and chemical copper properties^[4]

Atomic number	29
Atomic mass	63.546 g.mol ⁻¹
Electronegativity according to Pauling	1.9
Density	8.9 g.cm ⁻³ at 20°C
Melting point	1083 °C
Boiling point	2595 °C
Vanderwaals radius	0.128 nm
Ionic radius	0.096 nm (+1) ; 0.069 nm (+3)
Isotopes	6
Electronic shell	[Ar] 3d ¹⁰ 4s ¹
Energy of first ionisation	743.5 kJ.mol ⁻¹
Energy of second ionisation	1946 kJ.mol ⁻¹
Standard potential	+ 0.522 V (Cu ⁺ / Cu) ; + 0.345 V (Cu ²⁺ / Cu)
Discovered by	The ancients

Experimental

After many trails, the preparative parameters of the system were optimized to obtain, uniform, pinhole free and adherent thin films.

Spray solution is prepared by mixing 0.1 M aqueous solution of $\text{SnCl}_2 \cdot 2\text{H}_2\text{O}$ in 100 ml redistilled water on glass substrates. Also various doping concentrations with CuCl_2 have been achieved by changing volume percentage in the precursor solution.

Atomized spray solution was transferred to the borosilicate glass substrate, which was kept at normalized deposition temperature of 773 K with the help of carrier gas (air) the films were prepared at different substrate temperatures to obtain polycrystalline film.

The solution flow rate and gas pressure were kept constant at 10 ml/min and $1.2 \times 10^5 \text{ N/m}^2$ respectively.

The spray time was kept constant for 10 seconds throughout the deposition. An increase in the spray time causes thermal shock of the substrate due to excessive cooling.

A two minutes waiting time was allowed between each spraying application in order to maintain the substrate temperature and enable us to decompose the starting material completely.

The distance between the substrate and the nozzle was kept at 28 cm. The substrates are rotated intermittently to achieve uniform deposition. After deposition films were allowed to cool slowly to the ambient temperature.

Results and Discussions

This unit presents the results and the analysis of experimental measurements and tests of optical properties of the deposited films.

The optical properties include absorption, transmittance, absorption coefficient, direct allowed transition, direct forbidden transition, Reflectance, extinction coefficient, Refractive index, Real and Imaginary part of dielectric constant, as a function of photon energy.

Absorptivity

There are many influences which are responsible for the absorption like thickness, wave length of incident ray and color of material.

In this paper absorption has been measured as a function of wave length (300-900)nm, which appears in fig(2), calculation shows that absorption decreases with doping after the wave length (300) nm and increases before it .

Transmittance

Transmittance has been measured as a function of wave lengths (300-900)nm, for pure (SnO_2) and for that doped with (Cu), fig (3) show that transmittance increases with doping after the wave length (300) nm and decreases before it .

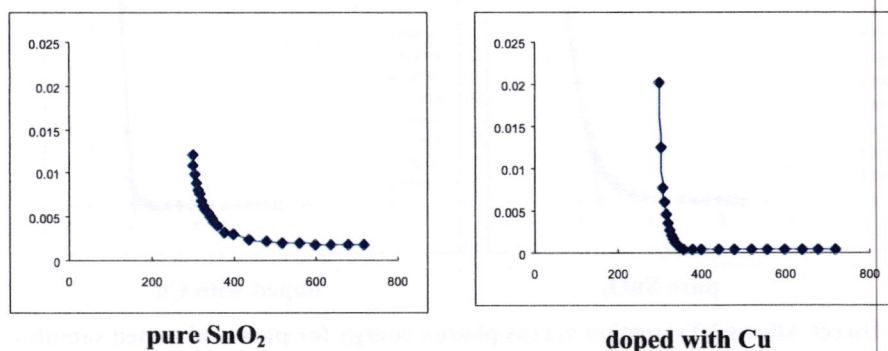


Fig (2) Absorption versus wave length for pure and doped samples

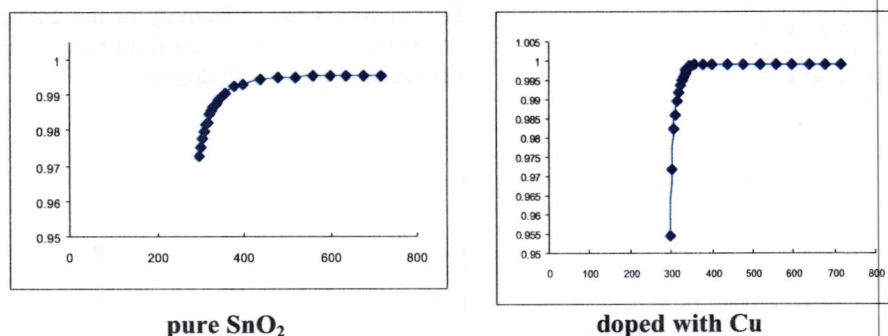


Fig (3) Transmittance versus wave length for pure and doped samples

Absorption Coefficient

The absorption coefficient was calculated using the equation :

$$\alpha = \left(\frac{2.303A}{t} \right)$$

Where:

α : photo absorption coefficient which changes with the incident wave length upon the material.

t : thickness of samples.[5]

Fig.(4) shows the relation between absorption coefficient and photon energy for two samples. It is clearly seen that the absorption edge is not sharp for pure sample and this may be related to the polycrystalline structure of thin films.

The observed absorption edge lies at 3.5 eV for undoped tin oxide and on doping it shift toward higher energies,

which is due to Moss-Burstein effect. [6]

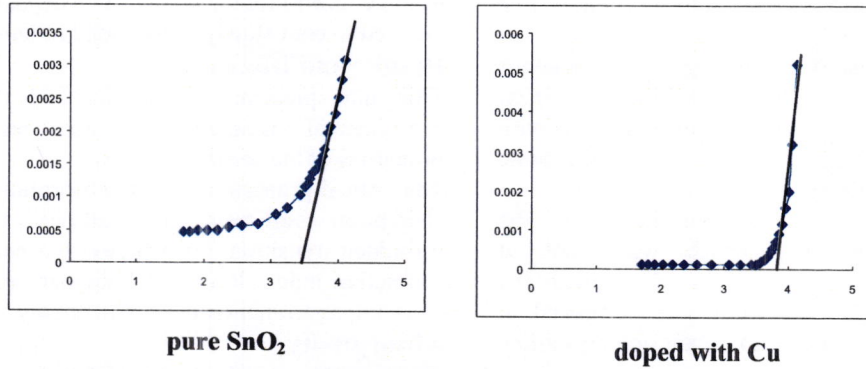


Fig (4) Absorption coefficient versus photon energy for pure and doped samples

Direct Allowed Transition

The direct allowed transition was calculated using the relation:

$$\alpha h\nu = A_0 (h\nu - E_g)^r$$

Where:

h : Plank constant .

A_0 : constant .

r : (1/2 , 3/2 , 2 , 3)

ν : frequency of incident light .

The direct allowed energy gap was determined by plotting $(\alpha h\nu)^2$ as a function of photon energy ($h\nu$) and were shown in fig.(5), the band gap energy (E_g) was determined by extrapolation of the straight line region of the plots $(\alpha h\nu)^2$ versus photon energy ($h\nu$). The direct band gap was found 3.8 eV for pure sample and 4 eV for doping sample. The increase in band gap can be attributed to the Burstein-Moss shift. [7].

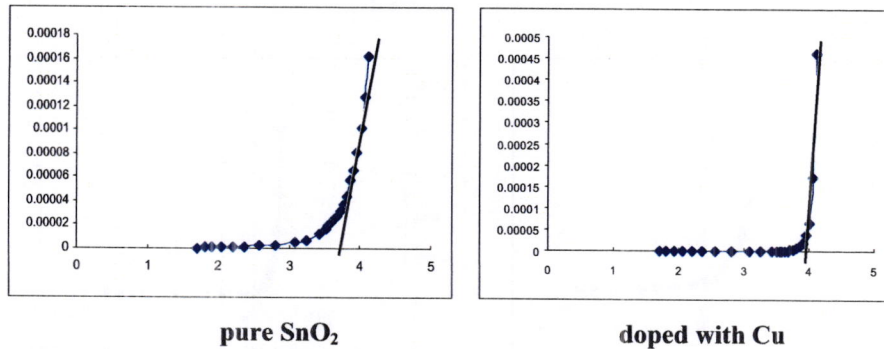


Fig (5) Direct Allowed Transition versus photon energy for pure and doped samples

Reflectivity

Reflectance was calculated using equation:

$$R = \left| \frac{1 - n^*}{1 + n^*} \right|^2 = \frac{(1 - n)^2 + n^2 k_o^2}{(1 + n)^2 + n^2 k_o^2}$$

Where:

n : real refractive index.

n^* : complex refractive index.

K_o : Extinction coefficient.[8]

Fig.(6) shows the reflectivity of the undoped and doped tin oxide. it is clearly seen from this fig. that reflectivity decreases slightly with doping .

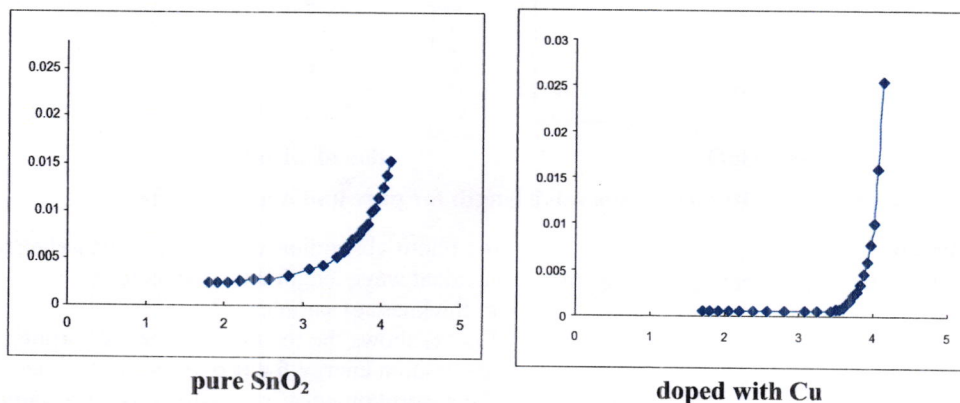


Fig (6) Reflectivity versus photon energy for pure and doped samples

Extinction Coefficient

The extinction coefficient (k_0) was calculated using the relation :[9]

$$k_0 = \alpha \lambda / 4\pi$$

Fig. (7) shows the variation of extinction coefficient as a function of photon energy for all the doped and undoped

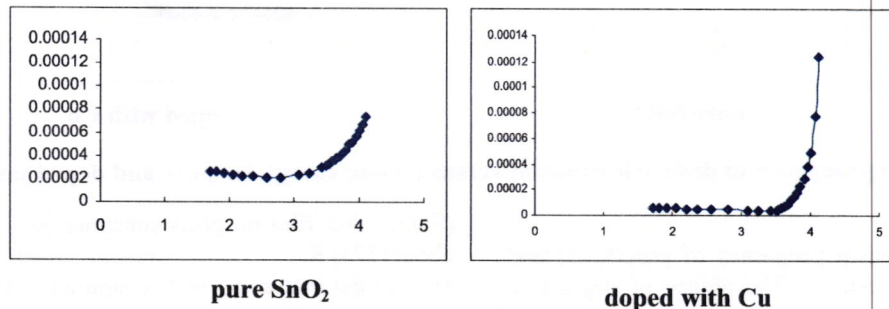


Fig (7) Extinction Coefficient versus photon energy for pure and doped samples

Refractive Index

Refractive index was calculated by means of equation: [9]

$$n_o = \left[\frac{(1+R)^2}{(1-R)^2} - (K_o - 1) \right]^{1/2} + \frac{(1+R)}{(1-R)}$$

tin oxide samples. The data of k_0 shows that the value decreased after doping, k_0 decreased very slightly as a function of photon energy in the low photon energy range and increased rapidly in the high photon energy range.

In fig. (8) the refractive index versus as a function of photon energy. refractive index decreased very slightly as a function of photon energy in the low photon energy range and increased in the high photon energy range

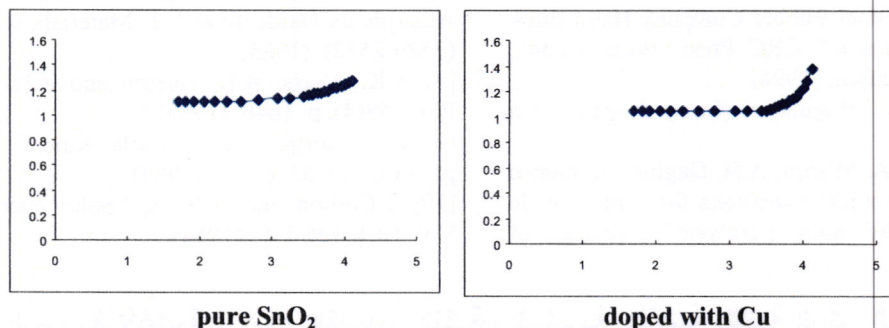


Fig (8) Refractive Index versus photon energy for pure and doped samples

Dielectric Constant

Real and imaginary part of dielectric constant were calculated using the equations:[10]

$$\epsilon_1 = n_o^2 - k_o^2$$

$$\epsilon_2 = 2 n_o k_o$$

Figs. (9) and (10) show the plots of real and imaginary parts of the undoped and doped samples. All the samples real and imaginary parts decreased after doping.

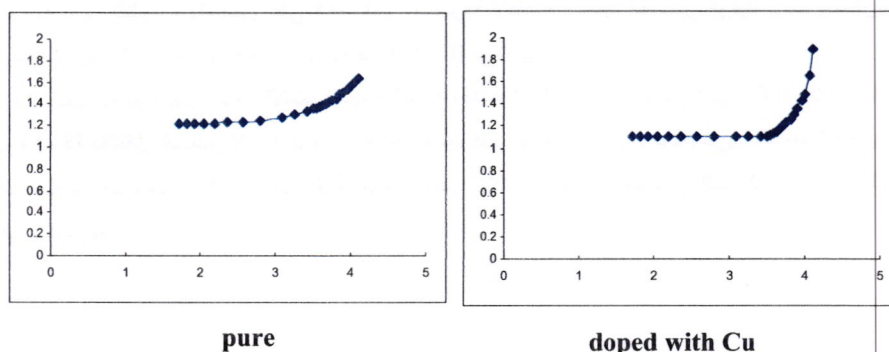


Fig (9) Real part of dielectric constant versus photon energy for pure and doped samples

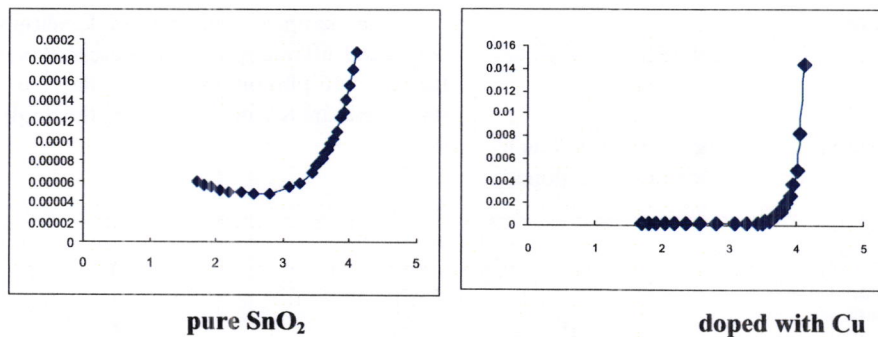


Fig (10) Imaginary part of dielectric constant versus photon energy for pure and doped samples

Conclusion

from the study of optical properties of pure(SnO₂)and doped with (Cu) we can get The ability of deposition

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(SnO₂) thin film on glass substrate in high temperature about (773)'K.

also we get increasing in Transmittance, Reflectivity and Energy Gap. But there is decreasing in other optical properties and constants.

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الخصائص البصرية لأغشية أكسيد القصدير النقية والمشوبة بالفضة بتقنية الرش الكيميائي الحراري

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المخلص

في هذا البحث تم دراسة تأثير التشويب بالنحاس على الخصائص البصرية لأغشية أكسيد القصدير الرقيقة وبطريقة الرش الكيميائي الحراري وعلى قواعد زجاجية وبدرجة حرارة 773 درجة مطلقة وبمولارية قدرها (0.1) مولاري . وللحصول على الثوابت البصرية تم تسجيل طيف الامتصاصية والنفاذية وللأطوال الموجية المحصورة بين (300-720) نانو متر . وقد وجدت قيمة فجوة الطاقة للانتقال المباشر 3.8 إلكترون . فولت للغشاء النقي و 4 إلكترون . فولت تقريباً للغشاء المشوب . وكذلك تم في هذه الدراسة حساب معامل الامتصاص والانعكاسية ومعامل الانكسار ومعامل الخمود وثابت العزل بجزييه الحقيقي والخيالي كدالة لطاقت الفوتون للعينات النقية والمشوبة .