The Effect of Protective Coatings on Mirrors Reflectance of Nd-YAG Laser Resonator

طلاءات الحماية على انعكاسية مرايا أشعة ليزر النديميوم- ياك

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ABSTRACT:

Optical coatings of dielectric materials of MgF_2 and SiO_2 have been used to reduce the effect electric field intensity of pulsed laser radiation and atmospheric conditions (oxidization) on metallic coatings (Ag and Au). The spectral characteristic of the reflectance curve for the preparation specimen in the visible and infrared regions in the range (400-1200)μm were studied. The effect of incident radiation of Nd-YAG laser has been studied and the value of threshold was determined and equal (10-16J/cm^2). The prepared reflectors and mirrors were used in construction of Q-switched Nd-YAG laser and to obtained the output pulses laser with energy(10-100mJ) and pulsed duration (30 ns).

الخلاصـــــة:

استخدمت الطلاءات البصرية للمواد العازلة(MgF_2 , SiO_2) لتقليل تأثير شدة المجال الكهربائي لأشعة الليزرالنبضية وكذلك الظروف الجوية (الأكسدة) على الطلاءات المعدنية (Au , Ag). تم دراسة درست الخصائص الطيفية لمنحنى الانعكاس للعينات المحضرة في منطقة الطيف المرئي وتحت الحمراء القريبة (400-1200)μm. تم دراسة تأثير أشعة الليزر (Nd-YAG) الساقطة على هذه المكونات وحددت قيمة العتبة لتلف الحاصل بـ (10-16)J/cm^2. استخدمت العواكس والمرايا المصنّعة في بناء فجوة ليزر (Nd-YAG) ذو التشغيل المفتاحي والحصول على نبضة ليزر خارجة بطاقة (10-100)mJ وأمد النبضة (30)ns.

1- INTRODUCTION:

Metallic coatings are very broadband applications and its reflectors and mirrors are also designed for different regions of the spectrum. Dielectric materials have a high melting point values and its thin film coatings with single and multi-layers offers excellent performance over a specific wavelength range, superior durability and damage resistance [1,2]. The use of metal thin films as high reflecting surfaces has been known for a long time.The spectrum performance of some common metal reflectors is shown in fig.(1) [3]. The wide range of constant reflectance of metal film is very useful in applications such as neutral mirrors, neutral beam splitters, and neutral density filters. Metal layers can be protected and their reflectance enhanced over a limited spectral range by using suitable dielectric coatings such as SiO, SiO_2, MgF_2 and Al_2O_3 fig.(2)[4]. Such highly reflecting systems with very low absorption are possible through the use of dielectric films.[5] Bare aluminum has a very high reflectance value, but will oxidize over time. Protected aluminum (752±10 Å) of SiO_2 film and (112±20 Å) of MgF_2 film is much preferred over bare aluminum [5]. Since its dielectric over coat arrests the oxidation process with minimal sacrifice in performance, Bare gold provides consistently high reflectance in the near - IR to far – IR and is the most widely used material in these regions. However, bare gold is very soft and is easily scratched. Protected gold has significantly better abrasion resistance than bare gold, and offers similar performance up to a wavelength of 16μm[7]. Silver coatings are used as surface coatings, such as Q-switched laser (reflectance cavity and total reflection mirrors) . Protected silver offers superior reflectance to aluminum [2,6,7]

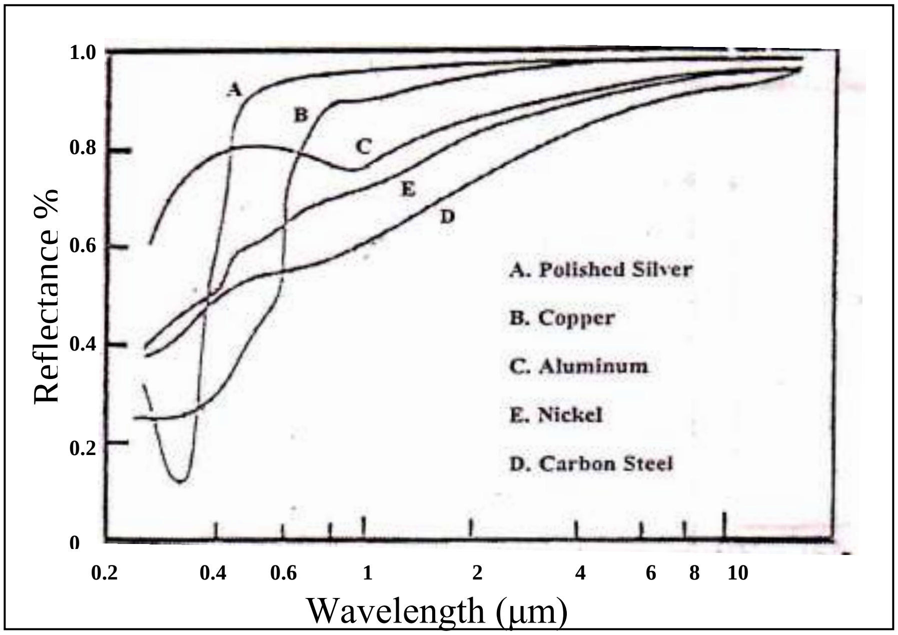

Fig.(1) The reflectance of some metal reflectors[3]

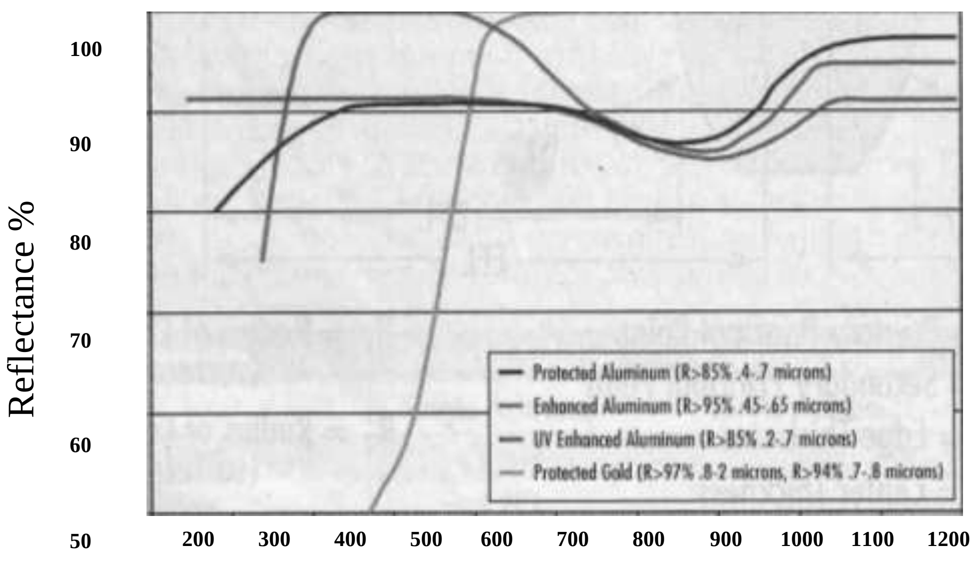

Fig.(2) The protected coatings of some common metal reflectors[4]

2- THEORETAL PART

ONE: DIELECTRIC COATING FUNDAMENTALS

The reflection properties of a coating are dependent upon the wave length of light being used, the refraction index of the substrate, the refraction index of the coating, the coating thickness and the incident angle of light. The equation for determining the index of thin film (the optical thickness of coating must be an odd number of quarter wavelengths) needed for complete cancellation of the two beams is[8]:

$$n_f = (n_o \times n_s)^{\frac{1}{2}} \qquad \text{(1)}$$

where n_f is the refraction index of thin film.
n_o is the refraction index of air (or incident material).
n_s is the refraction index of the substrate.

The use of single quarter-wave films of index higher than the substrate for boosting its reflectance has already been expressed in following equation:

$$R = \frac{(n_f - n_s)^2}{(n_f + n_s)^2} \qquad \text{(2)}$$

Consider now an assembly of an odd number of quarter-wavelength thick dielectric layers of indices n_H and n_L (high and low refraction index respectively) on substrate of index n_s. The normal reflectance at λ_o in air is:

$$R = \left[\frac{1-(n_H/n_L)^{2\ell}\,(n_H^2/n_s)}{1+(n_H/n_L)^{2\ell}\,(n_H^2/n_s)}\right] \qquad \text{(3)}$$

where ℓ is an odd number of quarter wavelength dielectric layers.

TWO: LASER INDUCED DAMAGE in THIN FILMS:

There have been a number of studies and review articles [7,8] published with the last few years discussing the laser damage to dielectric coatings [ThF_4 , SiO_2 , MgF_2 , Al_2O_3 , CaF_2 , ZrO_2 , TiO_2 , SiO , LiF , MgO , CeO_2 , ZnS]. Laser damage threshold measured in evaporated thin films and multilayer coatings on glass substrates are reported in previous studies [9,10], of values from about 350 J/cm² for SiO_2 and MgF_2 films through 200 J/cm² for ZrO_2 to about 30 J/cm² for ZnS films. In several studies [11], the damage threshold of 95% reflecting, multilayer, and dielectric coatings exposed to ns pulses from a TEM Nd-YAG laser was measured. Depending on film composition and number of layers, the damage thresholds obtained by focusing the beam to spot sizes of the order of 0.1 to 0.2mm ranged from 0.6 J/cm² to 2.9 J/cm² for the mode-locked laser, and from 16 J/cm² to 58 J/cm² for the normal Q-switched system. A little data of discrete values such as optical and physical thin film thickness which are available on the optical properties of MgF_2-Ag and SiO_2-Au laser mirrors and reflectors. This paper describes the design and technical procedure which endeavors fill this need.

3- EXPERMENTAL PROCEDURE and MEASUREMENTS:

ONE: COATING SUBSTRATES:

Glass of BK-7 substrates have been prepared of different diameter and (1mm) thickness. Also we prepared a quartz tubes as opened cylindrical substrates. These samples or substrates have been cleaned by water washing for 5 minutes and mixed in the ultrasonic path for 15 minutes. Finely, the substrates washed by high purity alcohol and baked in thermal oven at 80 °C for 30 minutes.

TWO: COATING UNIT:

Vacuum coating unit (model BAE080) of Balzer company was used to deposit coating layers as per coating design. Table (1) shows the physical & optical thickness of deposited thin films which measured by using a quartz-crystal oscillator thickness monitor on coating champers. Just as with protection coatings, laser resonator mirror, and reflector coatings are designed for region of spectrum

(400-1200)nm. Protected silver and gold are our most popular mirror and reflector coating consist of silver and gold with a quarter-wavelength MgF_2 and SiO_2 over coat.

Table (1) Illustrated the optical and physical thicknesses of coating layers

Symbol	Material	Thickness
H	AG	1.0000 qw
L	MGF2	1.0000 qw

Layer	Material	QWOT	Thickness(nm)
1	AG	1.0000	2241.62
2	MGF2	1.0000	192.75
3	AG	1.0000	2241.62
4	MGF2	1.0000	192.75

Symbol	Material	Thickness
H	AU	1.0000 qw
L	SIO2	1.0000 qw

Layer	Material	QWOT	Thickness(nm)
1	AU	1.0000	1310.09
2	SIO2	1.0000	185.50
3	AU	1.0000	1310.09
4	SIO2	1.0000	185.50

The reflectance spectrum of all samples were determined using reflect meter (Lambda-9) as shown in figs. (4,5).

Our metallic mirrors and reflectors of MgF_2-Ag and SiO_2-Au fig.(6) were constructed to use as laser components in Q-switched Nd-YAG cavity. The laser pulse output prepared cavity (laser rod L=8mm, ϕ=4mm) is closed to pulse energy of (20-30)mJ and duration of 30nsec. as shown in figs. (7,8). The Joule meter of ED-500 and photodiode detector (SGD-100) were used to measure the output pulsed energy and duration respectively of oscillator laser pulse.

The damage threshold obtained by incident laser beam to spot size of order 4mm. The approximate range of 10-16 J/cm^2 for MgF_2-Ag and SiO_2-Au coatings.

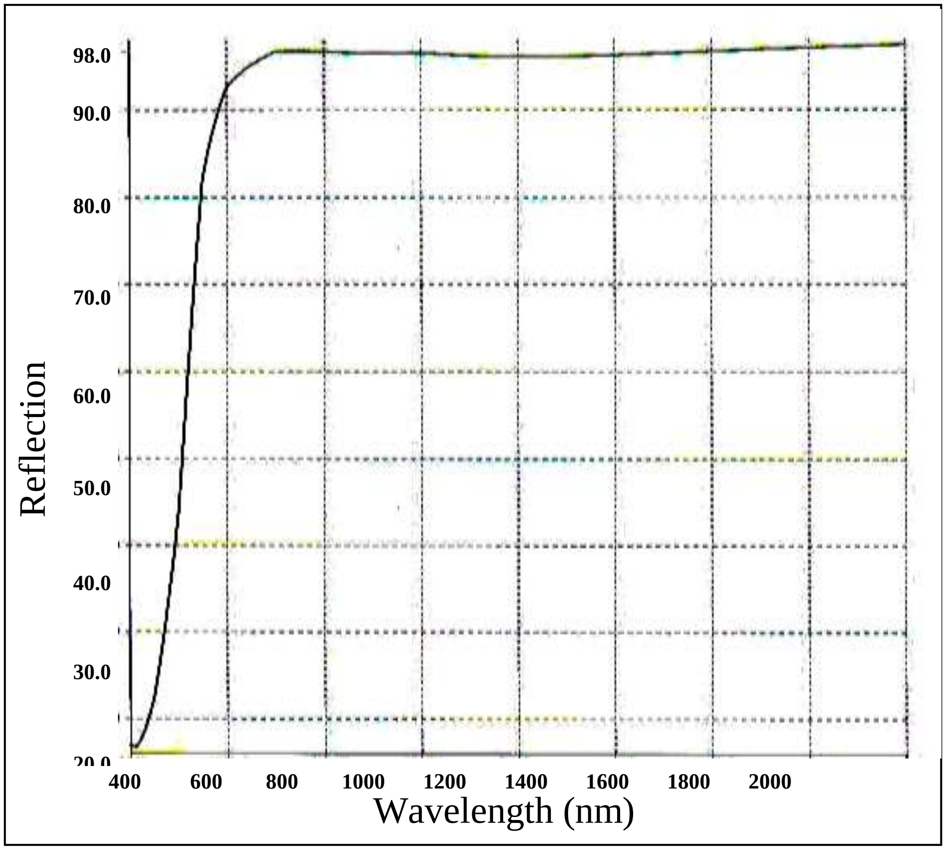

Fig.(4) The reflectance spectrum of MgF_2-Ag reflectors

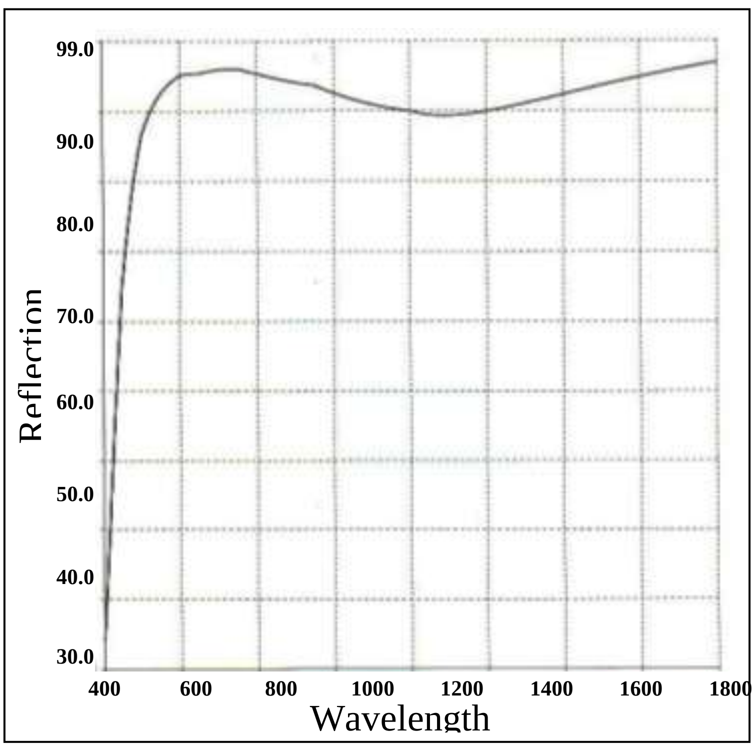

Fig.(5) The reflectance spectrum of SiO_2-Au reflectors

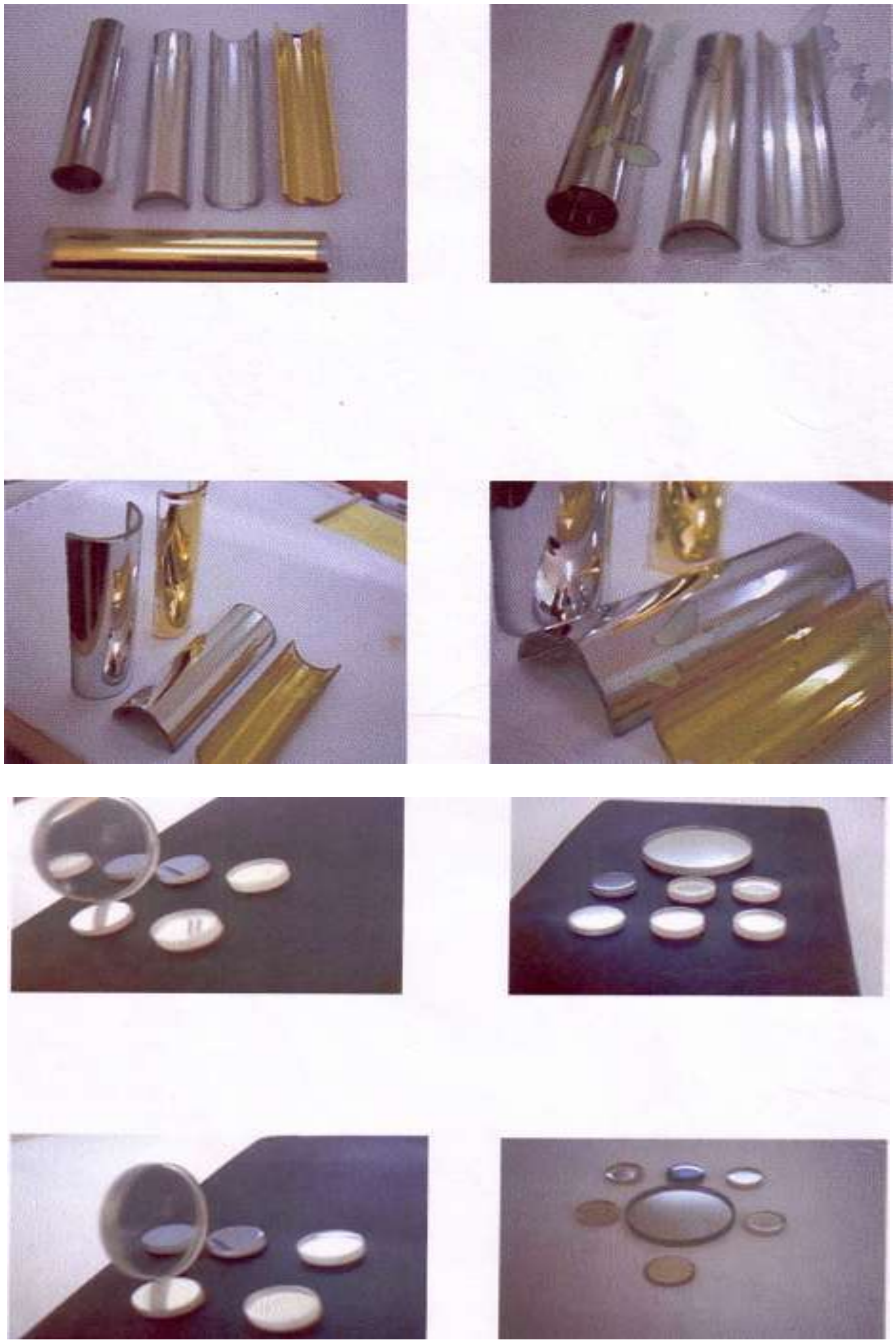

Fig.(6) Shows our metallic mirrors and reflectors of MgF_2-Ag and SiO_2-Au

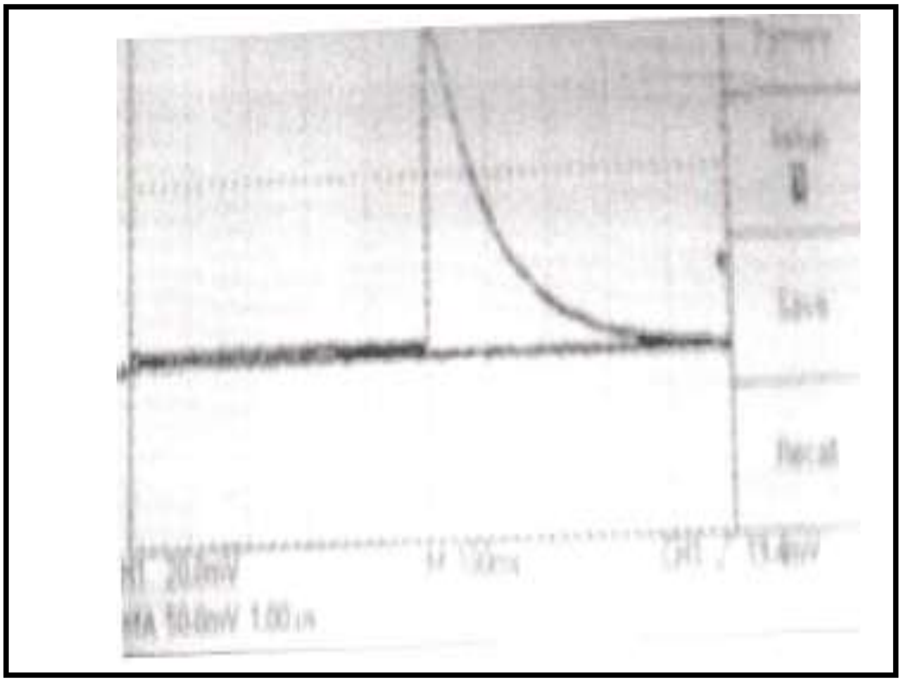

Fig.(7) The pulse laser energy from energy detector

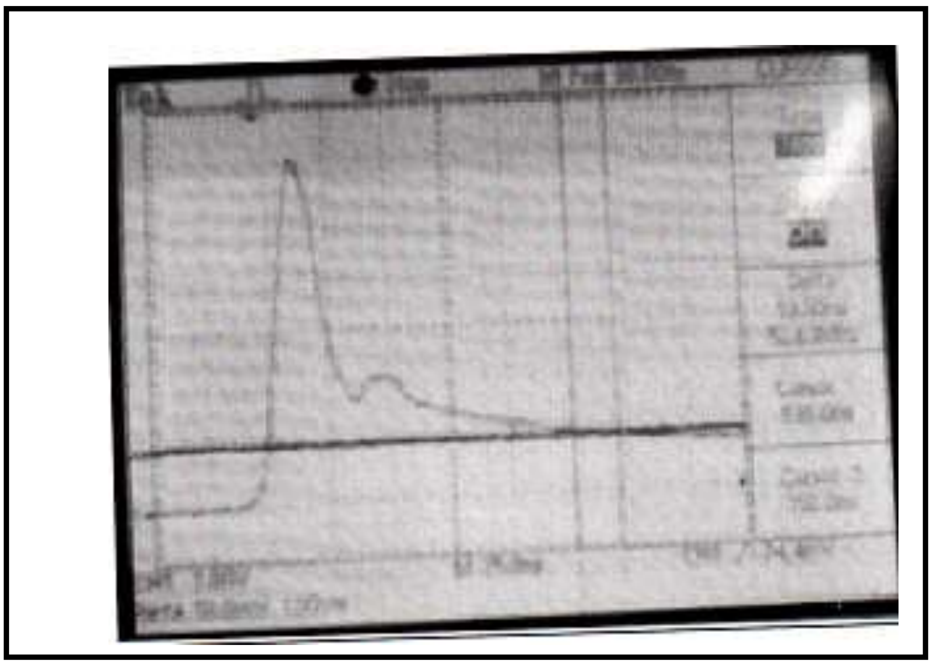

Fig.(8)The laser pulse duration received by photo detector

4-DISSCUSION of RESULT and CONCLUSIONS:

Our results of protected silver coatings offers superior reflectance to aluminum of previous studies and optical products [5,7]. However, its strong tendency to oxide and tarnish means that it must be throatily sealed from the atmosphere in order to avoid degradation. In comparison of other dielectric metallic coatings [12], the laser damage threshold in samples reported in this paper is superior in the applications of laser devices.

1-In the measurement reported in this paper, the all samples were characterized in range of (400-1200)nm wavelength.

2-The protected coatings provides high reflectance percentage in the visible and near infrared region and sharply determent in the region (<400nm) through the ultraviolet range.

REFERENCES

1- W.B. Elmer, "The Optical Design of Reflectors", John Wiley & Sons, New York, (1980).
2- K.H. Choi, J.Y. Kim, Y.S. Lee and H.J. Kim, Thin Soild Films, Vol.341, 152 (1999).
3- G. Hass, J. Opt. Soc. Am.Vol. 45, 1, 945, (1955).
4- Edmund Optics: Optics and Optical Instruments Catalog, 19, (2003).
5- H.E. Bennett. Jean M. Bennett, and E.J. Ashley, “Appl. Opt.”, Vol.2, No.1, 158, (1963).
6- R.K. Roy, S.K. Mandal, D. Bhattacharyya and A.K. Pal, The European Physical Journal B.Vol.3,No.1,550,(2001)
7- Condensed Matter and Complex System., Vol,34,No. 1, 25, (2003).
8- J.T. Cox and G. Hass, "Physics of Thin Dilms", Vol.2, Academic Press, New York, 246, (1964).
9- J.H. Apfel, J.S. Matteucci, B.E. Newnam, and D.H. Gill, "The Role of Electric Field Strength in Laser Damage of Dielectric Multilayers", UBS special publication, (1976).
10- J.H. Apfel., “Appl. Opt.” Vol.16, No. 7, 1880, (1977).
11- J.R. Betti, R.A. HouseII and A.H. Guenther, "Spot Size and Pulse Duration Dependence of Laser Induced Damage", UBS special publication, (1976).
12- Melles Griot: MAXBRte Coating: A5:32, (1988).