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Laser Damage Measurements in Glass Substrates Coated by Metallic Films

T. El-Dessouki,* F. Sharaf, I. Fouda*** and N. Khalil***

**Faculty of Science, King Abdulaziz Univ., Jeddah, Saudi Arabia;*
***Atomic Energy Establishment, Inshas, Egypt; and*
****Faculty of Science, Mansoura University, Mansoura, Egypt*

ABSTRACT. The thermal effect of a ruby laser on glass substrates coated by different thin metal films of silver, copper, aluminium, nickel, chromium and antimony is studied. It is shown that the depression in the damaged area is linearly dependent on the thickness of the metal films as well as on their thermal conductivities. The depressions are found to be greater than those produced in uncoated glass.

Although the laser has already become a widely used tool in metalworking, its application for specific problems is still a matter of trial (Allingham *et al.* 1973, Chik 1974 and Chez *et al.* 1974). High power lasers are already gaining acceptance in such material processing areas as deep penetration autogenous welding, cutting, drilling, transformation hardening and experimental shock hardening. The very high power density of lasers also allows melting to be localized at the surface, thereby establishing high cooling rates. In the process called 'Laser glazing', the extremely rapid chill rates of thin molten zones have produced a variety of novel, extremely homogeneous metallurgical microstructures (Breinan *et al.* 1976 and Von Allmen 1976). The laser glazing process is a new and elegant method for reproducibly and controllably attaining rapid solidification and solid-state cooling of materials. The technique of laser glazing involves rapidly traversing the surface of material with a laser beam focused to a power density in the range of 10^4-10^7 W/cm^2.

For a full understanding of the laser metal interaction, two important aspects have yet to be properly explained. The first, and probably the most important for practical purposes, is the thermal effect of the laser on dielectric substrates coated by different thin metal films. Such measurements are useful in the spectral analysis of metallic coatings on glass, ceramics and insulating materials. The second aspect is the connection between the power density of the source and the evaporated material from the resultant crater. These two effects are treated in this paper.

Damage Measurements and Analysis

For spectrum analysis of metallic coatings on dielectric substrates using a Laser Microspectral Analyser (LMA 1), glass slides were coated with different thin metal films. The glass plates were coated with either silver, copper, aluminium, nickel, chromium or antimony of thermal conductivities 4.29, 4.01, 2.37, 0.909, 0.939 and 0.244 W $cm^{-1}K^{-1}$, respectively, at room temperature (Robert 1976). Then, the target was subjected to the focused Q-switched ruby laser pulse at an applied flash tube voltage of 2.0 Kv. This laser pulse intensity was $\simeq$ 10 MW/cm^2 with duration time of 30 nsec. The laser radiation emitted was focused onto the surface of the target within an area of 250 μm in diameter by using an objective lens $\times$ 16/0.2. The thicknesses of the coatings, which were prepared by vacuum deposition, ranged from 0.01 μm to 0.28 μm. It was found that in all cases a crater was formed

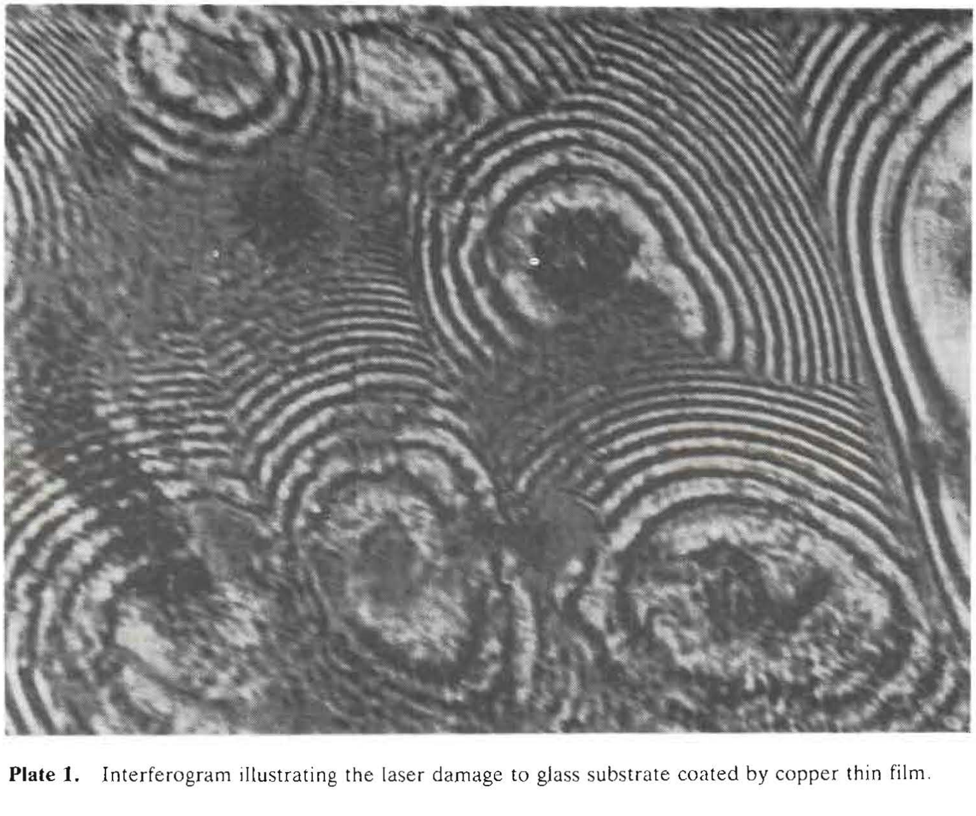

Plate 1. Interferogram illustrating the laser damage to glass substrate coated by copper thin film.

not only in the metallic films but also in the glass substrate. The resultant damage in the surface of the targets is mainly due to the thermal effects of the laser beam. The depth of the crater created in the targets is of profound importance in spectral analysis of inhomogeneous material, as that evaporated from the induced pit is allowed to feed the electrode gap.

The damaged regions were examined interferometrically by applying multiple-beam Fizeau fringes at reflection (Barakat *et al.* 1980). Interferogram (1) shows the contouring fringes corresponding to the damage resulting from irradiating copper coating of thickness 0.056 μm by a focused ruby laser pulse. The resulting interferograms consist of clusters of closed contouring fringes at different levels. These groups of contouring fringes, corresponding to the hills inside the irradiated area, were observed also by scanning electron microscope.

Plates 2 and 3 illustrate the scanning electron microscope cross section inside and outside the induced pits resulting from irradiating aluminium and silver coatings, respectively, by focused pulse from ruby laser source. Not only was material removed from the center of the damaged area but it was also redistributed, forming many hills inside the irradiating area as shown in Plate 2. It should be mentioned that at the applied intensity of maximum efficiency, *i.e.* at 10 MW/cm^2 splashes of resolidified material were deposited around the edge of the holes as shown in Plate 3.

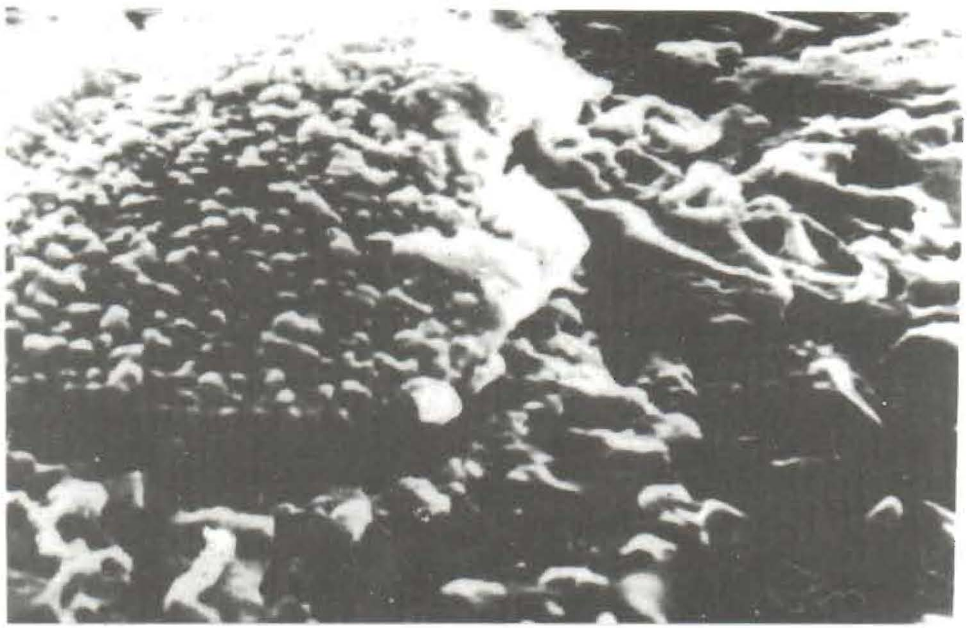

Plate 2. Electron-Micrograph inside the pit of glass coated by aluminium thin film.

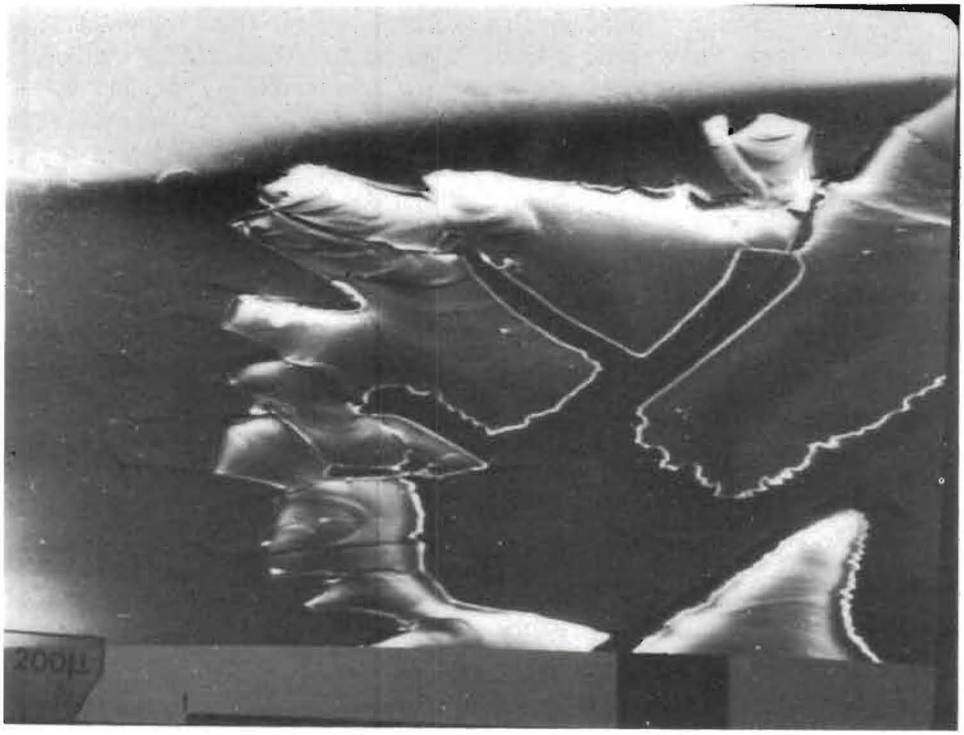

Plate 3. Electron-Micrograph showing the distribution of the material outside the pit of glass coated by silver thin film.

Figure 1 shows the dependence of the resulting depression in the glass substrate on the thickness of the metal films. The depth of the craters was found to increase linearly with increasing the metal film thickness.

The three curves of silver, copper and aluminium which are good thermal conductors, intersect at a common point of 0.029 μm metal film thickness. The other curves of nickel, chromium and antimony, which are low thermal conductors intersect at another common point of 0.04 μm metal film thickness. However, the damage to the glass substrate, coated by an absorbing metal film $\geqslant$ 0.029 μm for good conductors and $\geqslant$ 0.04 μm for low thermal conductivity conductors, was greater than the damage of uncoated glass; when the laser pulse intensity was kept constant (10 MW/cm^2).

Moreover, the resultant damage for a laser pulse in a glass substrate coated by a metal film may depend on its thermal conductivity as well as its reflectivity. However, reflectivity does not change the absorbed energy from the laser pulse, since it is known that the reflecting power of a metal decreases significantly as the

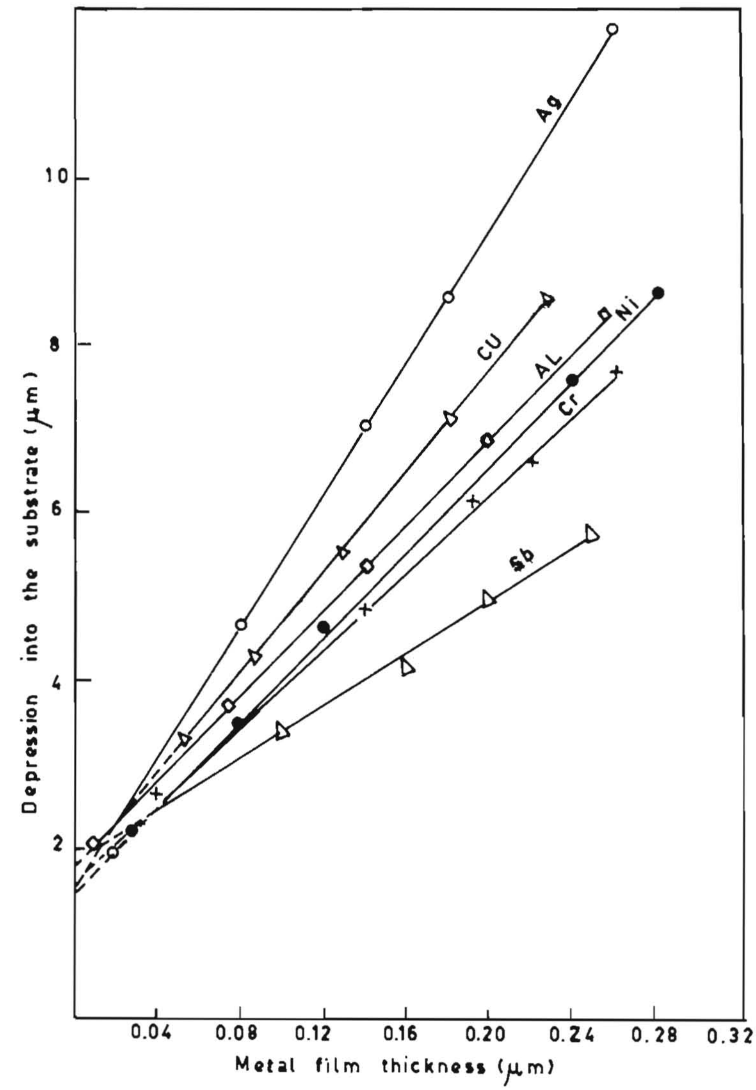

Fig. 1. The relation between the maximum depression into the glass substrate and the metallic film thickness.

temperature is increased up to and above the melting point (Bonch-Bruevich *et al.* 1968).

Hence, the dependence of the maximum depression in the glass substrate on logarithm of the thermal conductivities of the six metal films is shown in Fig. 2. The abscissa of Fig. 2 illustrates relative thermal conductivities with respect to

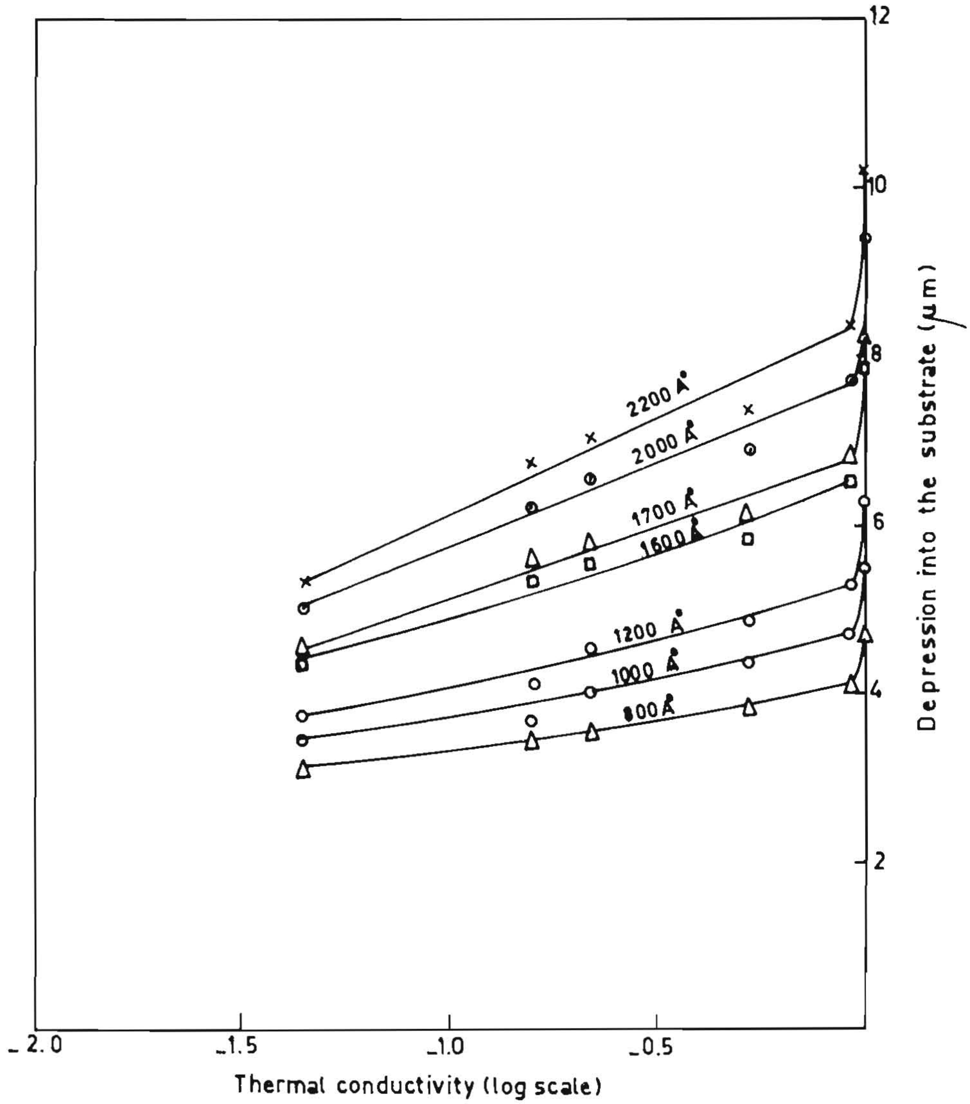

Fig. 2. The relation between the maximum depression into the glass substrate and the logarithm of thermal conductivity.

silver. These relations are illustrated at different metal film thicknesses: 0.08, 0.10, 0.12, 0.17, 0.20 and 0.22 μm, respectively. The depression is linearly proportional to the thermal conductivity up to 0.22 μm thickness. In Fig. 2, when the metal film thickness increases above 0.12 μm, the divergence of the experimental points from linearity also increases.

The greatest interest in this curve is that the maximum depth increases abruptly from copper to silver. This means that for a high thermal conductivity material, *i.e.* silver, the local heat concentration of a laser beam into the target is much greater than for the other materials. This is also shown in Fig. 1, where the silver curve is steeper than the curves of the other five materials.

These observations illustrate that the thermal effect of laser on a glass substrate depends on the physical properties of the metal film, especially its thermal conductivity.

Conclusion

From the measurements carried out in the present work to investigate the damage in glass substrates due to the thermal effect of a laser beam, the following conclusions are drawn.

1. The depression of the resultant crater was found to be linearly dependent on the thickness of the metal films as well as on their thermal conductivities.

2. While the laser pulse intensity was kept constant, the damage in the glass substrate coated by an absorbing metal film of thickness d ($0.26 \geqslant d \geqslant 0.029$ μm for silver, copper and aluminium, and $0.28 \geqslant d \geqslant 0.04$ μm for nickel, chromium and antimony) was greater than the damage of uncoated glass.

3. The evaporated material was not only removed from the center of the damaged area, but also redistributed itself forming many hills inside the crater.

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قياسـات إتـلاف الليـزر فى الـزجاج المغطى بشرائح معدنية

توفيق الــدســوقى* ، فؤاد شرف ، إبـراهيم فودة*** ونجوى خليل***

** كلية العلوم - جامعة الملك عبد العزيز - جدة المملكة العربية السعودية*

*** مؤسسة الطاقة الذرية - انشاص - مصر*

**** كلية العلوم - جامعة المنصورة - المنصورة - مصر*

دُرس التأثـير الحـرارى لشعـاع الليـزر السـاقـط على زجـاج مغطى بشـرائـح رقيقة من معادن الفضة والنحاس والألومنيوم والنيكـل والكروم والأنتيمون . وُجد أن عمق الإتلاف الناتج يتنـاسب خطيـاً مع سمـك الشـرائـح المعـدنيـة وكـذلك مع معـامـلات توصيلهم . كما أن عمق الإتـلاف داخـل الزجاج المغطى بالشـرائـح المعـدنية يكون أكبر من الإتلاف الناتج فى الزجاج غير المغطى .