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Thirty-seven years of lasers in the conservation of art

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Sumario. En los últimos 37 años diferentes técnicas láser han mostrado ser útiles en la práctica de la conservación del arte. Incluyen la limpieza fotónica y decapado, display holográfico y análisis no destructivo, caracterización de superficies mediante fluorescencia láser, dispersión y absorción de la radiación, y ultrasonido inducido por láser. A pesar de la amplia utilidad del diagnóstico basado en láser en el arte y la arqueología, el impacto mayor ha sido en el decapado y limpieza. La ablación por láser se ha usado en la conservación de sustancias como la piedra, el terracota, bronce, hierro, plomo, artículos de madera, manuscritos, pergamino, vitela, papel, cuero, textiles, y superficies pintadas. Los contaminantes superficiales que han sido removidos incluyen depósitos calcáreos, sulfatos, óxidos, musgo, líquenes, hollín, tierra, barnices deteriorados y pinturas superpuestas. La remoción con láser se ha empleado con éxito prácticamente con cualquier tipo de objeto museable y en numerosos edificios históricos y contemporáneos. Con frecuencia se ha encontrado que el decapado con láser es menos costoso y riesgoso para las superficies sensibles y frágiles que los abrasivos tradicionales y los métodos de limpieza química.

Abstract. For the past thirty-seven years various laser technologies have demonstrated utility in the practice of art conservation, as well. These include photonic cleaning and divestment, holographic display and nondestructive analysis, surface characterization through laser fluorescence, radiation scattering and absorption, and laser-induced ultrasound. Despite the broad utility of the laser-based diagnostics in art and archaeology, the greatest impact of laser technology has been in divestment and cleaning. Laser ablation has been employed in the conservation of substances such as stone, terra cotta, bronze, iron, lead, wooden articles, manuscripts, parchment, vellum, paper, leather, textiles, and painted surfaces. The range of surface contaminants that have been removed include calcareous deposits, sulphation, oxidation, moss, lichens, soot, soils, deteriorated varnish, and over paints. Laser divestment has been employed successfully with almost every class museum object and on numerous classes of historic and contemporary buildings. Frequently, it has been found that laser divestment is both more cost effective and less hazardous to sensitive and fragile surfaces than traditional abrasive and chemical cleaning methods.

Key words. laser applications 42.62.Cf , optical holography 42.40.-i, laser impact on surfaces 79.20.Eb

1 Introduction

In the field of art conservation surface divestment frequently poses an array of vexing problems. It is not uncommon to find that an encrustation, over paint, corrosion layer, soil, or biological growth to be removed is more durable than its submerged artistic remnant. In traditional practice the various mechanical and chemical surface treatments often attack the overburden and substrate with comparable vigor. Customarily, it is a matter of observation, skill, and timing that leads to maximum divestment with minimum damage to the fabric of the artifact itself. The problem of ancillary damage to artwork surfaces during cleaning is exacerbated by collateral health hazards to workers. Protective equipment to shield conservators from vapors, chemicals, and dust can impede the observation and control needed for precise and optimum treatment. Consequently, there has been a prolonged interest in discovering a new divestment technology that is free of the limitations of conventional chemical, mechanical, and abrasive methods. One such candidate is radiation-induced divestment employing nontoxic and environmentally friendly photons.

The past one hundred years have witnessed the emergence of scores of new photon generators spanning the entire electromagnetic spectrum from radio waves to gamma rays. The most powerful and energetic of these photon sources are nuclear and thermonuclear explosive devices. One of the peaceful (Plowshare) applications of nuclear energy was the ORION rocket for deep-space exploration. This space vehicle was to be loaded with several nuclear explosive devices. One at a time they would be ejected from the tail of the vehicle and detonated at a distance. The X-ray photon flux from the explosion then ablated material from the tail of the ORION and the reaction force propelled the rocket forward. Such a rocket was successfully flown over the California coast forty years ago. Nevertheless, the Nuclear Test Ban Treaty dimmed the prospects for carrying out an Orion deep-space exploration mission to the planet Saturn.

However, serendipity took over at that point in a chain of "Connections" straight from Burke[1]. First, the laser was invented[2] at a site connected to the ORION Program and it became possible to simulate ORION in the laboratory with optical rather than X-ray photons[3]. Second, pulsed-laser holographic-interferometric techniques were developed and employed to characterize laser blow off plasmas, spacecraft dynamics, and rocket plumes[4]. Third, a massive radiation-hydrodynamic Lagrangian computer code (SPUTTER) was employed to guide the laser simulation experiments that led to the laboratory generation of micrometeorites ("surfing" the blow-off plasma) at a record velocity of 50mm/us[5]. (The computer modeling revealed that shockwave damage to laser-irradiated surfaces may be avoided by insuring that the plasma-pressure buildup time permits at least ten stress-wave transits of the body (viz., shockless acceleration)[6]. At the other extreme is thermal damage to the body which is avoided by requiring that the laser flux be high enough so that the sublimation-wave velocity is higher than that of the thermal conduction wave[7]. Fortunately, a variable pulse length Q-switched laser technology[8] was invented so that these conditions became attainable in surface irradiation experiments.)

The fifth "connection" shifted the scene to the CNR laboratory in Venice where a version of the radiation-hydrodynamic computer code was installed to support the lagoon-closure-gate program through modeling of the wind-driven storm tides of the Adriatic[9]. That collaboration stimulated further serendipity in the guise of a joint CNR/UCSD proposal to ENI (Rome) for the funding to an exploratory study on the feasibility of in-situ full-scale holographic archival recording of threatened Venetian statues and monuments. Immediately thereafter, the awarding of the Nobel Prize to D. Gabor for conceiving of holography[10] became the sixth link in the chain of events. With holography suddenly catapulted to the ranks of front-page news, evidently, ENI was unable to reject the proposal.

Figure 1. Dr. R. Wuerker, ruby laser, and Donatello statue.

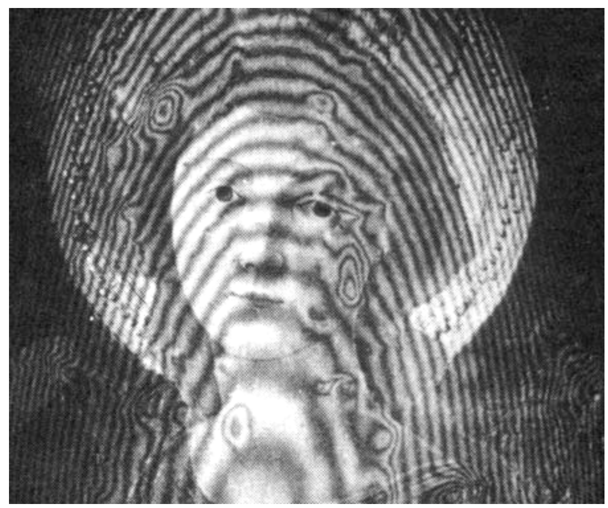


Figure 2. Holographic interferogram revealing paint-layer detachments.

The ENI-sponsored (US$7,000) holographic conservation study took place in the winter of 1971-72 and employed a 2J/pulse ruby oscillator/amplifier laser[11]. The holographic arrangement in San Gregorio together with the developer of the high coherence length pulsed laser, Dr. Ralph Wuerker, appear in Figure 1. A photograph of the reconstruction of one of the first in a series of Venetian holograms and interferograms is reproduced in Figure 2. The assemblage of scientists and conservators in San Gregorio was the seventh and final event in the bizarre linkage that began with nuclear propulsion in space and culminated in laser cleaning of stone sculpture

2 Stone cleaning in Venice

Toward the end of the holographic project in February 1972 Ms. G. Musumeci (conservator) returned to San Gregorio from a meeting of the Soprintendenza alle Gallerie e alle Opere d'Arte del Veneto with the suggestion that stone cleaning be attempted with the concentrated beam from the ruby holography laser. She explained that outdoor sculptures in Venice were being lost due to the failure of conservation projects to be granted official approval because available cleaning methods yielded unacceptable patinas.

In the months following the holographic effort K. Hempel (V&A Museum) shipped large numbers of relatively large (20-40cm) British and Italian stones to California for laser divestment. In late 1972 these were placed on the roof of the V&A Museum for protracted weathering tests. Some were consolidated and others were not. Unfortunately, K. Hempel retired from the conservation field shortly thereafter, and only a very few specimens were analyzed[12,13,14,15] before the entire set was discarded without notice by the museum.

In 1973 F. Valcanover conveyed an official request to the S.H. Kress Foundation for the acquisition of a laser statue cleaner for Venice. Toward this end the Foundation supported a one-year (1974) study at UCSD to determine the "safety of laser radiation for stone". Before and after laser irradiation, diverse Venetian stone specimens were analyzed by means of XRF, SEM, X-ray diffraction, optical microscopy, and electron microprobe. Based upon the test results[16] the Kress Foundation granted US$25,000 for the design, construction, testing, delivery, and evaluation of a first laser statue cleaner[17] in 1975 for the cleaning of small sculptural elements in marble.

After three years (1978) the Venice Statue Cleaner was retired. There were technical, organizational, and financial reasons for this outcome. Unfortunately, in that era efficient solid-state switching power supplies and simmer supplies were not available, nor were long-lived optical dielectric coatings. As the Kress Foundation had not provided for system maintenance, repair, or upgrade, these responsibilities fell upon the conservator (A. Martini). When the original supply of spare optical, electrical, and electronic components was exhausted he had no option but abandon the laser. Nevertheless, Mr. Martini was successful in laser-cleaning a great many small stone sculptural pieces[18] and buildings (see figure 3).

3 Exploratory materials research

Two years after the Venetian holography project a Center for Art Science Studies (CASS) with initial funding from the S.H. Kress Foundation and The National Endowment for the Arts (NEA) was established at The Scripps Institution of Oceanography (SIO) on the UCSD campus. Its charter was to train art conservators in advanced technologies. However, it was attached to GRD/SIO (Geological Research Division of SIO): a group with strong interests in marine archaeology, and managed by a group with strong interests in computer-generated performance art (Visual Arts Department).

Figure 3. First laser cleaner at Plaazzo Ducale, Venice.

In spite of the widely divergent interests of the organizations participating in CASS, two things were accomplished for the field of art conservation. First, CASS engaged the late G. Stout and the late R.Buck as consultants to establish the Balboa Art Conservation Center (BACC) in 1975. Second, a laser laboratory was assembled to study the interaction of laser radiation with artistic materials.

The CASS laboratory (1974-78) was equipped with ruby (harmonic capability), Nd:glass, Nd:YAG (harmonic capability), TEA, flashlamp-pumped dye, and excimer (XeF and KrF) lasers as well as xenon flashlamps, argon theta pinchlamps, argon Z-pinchlamps, and surface flashover sparkboards. Testing could be performed in air (static or jet), vacuum, inert atmosphere, reducing atmosphere, or liquid (water or solvent). More than a thousand solicited and unsolicited specimens were sent from nineteen countries for radiation-divestment testing. Examples included parchment (see figure 4, where 350 nm radiation from excimer and YAG harmonic radiation yielded comparable results) and an embossed-leather book spine[19]. A large proportion of the materials received were soiled textiles. Invariably, short-pulse and short-wavelength treatment yielded the best results (see figures 5 and 6). Several of the rather large stone pieces received came from K. Hempel (1972-74). Many of these were consolidated and placed on the roof of the Victoria and Albert Museum for environmental exposure. Tragically, these were lost following his retirement.

When oxidation, redeposition, thermal alteration, or process rate were problematical the local environment was changed. An argon gas jet directed toward the laser spot often resolved the difficulty. Simply moistening the surface prior to laser treatment frequently helped. On occasion (especially with flashlamps) the irradiation had to be performed with the piece submerged entirely in water or an organic solvent such as Freon. The most complex of these cases was concerned with recovering the color of burned pigments as in the case of the restoration of the Qin-Dynasty Terra Cotta Warriors[20]. Other materials that were investigated included woods, papers, fossils, bones, sea shells, clay bricks, stucco, concrete, semi-precious minerals, pottery, ceramics, stained glasses, glass crystal, bronze, copper, tin, iron, silver, gold, aluminum, titanium, stainless steel, paints, fiberglass, and plastics.

On some occasions there were sufficient time and resources available to permit careful analytical analyses of the divestment results[21]. In these instances optical microscopy, electron microprobe, SEM, XRF, and X-ray diffraction observations were employed to the before and after surfaces as well as to blowoff debris. Many of these revealed that potentially hazardous gaseous and particulate substances were being ejected during the light treatment (see figure 7). Thereafter, the technology of laser pollution control has received serious attention[22].

A few fragments of the work indicated above were published in the conservation literature. However, the bulk of the data remain unpublished[22, 23] as the leading art conservation journal of that era (1973-78) would not submit the manuscripts to peer review as "...laser cleaning of artworks is too hypothetical to be taken seriously".

4 Early radiation-divestment projects

By 1978 the UCSD Visual arts Department absorbed CASS, renamed it CRCA (Center for Research on Computing in the Arts) in order to return to a focus on computer-generated art, and withdrew from BACC. The affiliated GRD/SIO personnel returned to full-time oceanography. With the demise of CASS the scientists and students who found themselves in limbo joined The Institute for Pure and Applied Physical Sciences (IPAPS) to pursue new interests in applying ultrasonic and thermal imaging to art conservation[24] and digital computer image enhancement to problems associated with the interpretation and restoration of paintings [25]. (These activities contributed to the establishment of the Associazione Italiana Prove Non Distruttive in 1983.)

Requests for radiation-divestment assistance continued to be directed to UCSD in spite of the demise of CASS. In 1978 UCSD faculty and students removed 4-9 layers of overpaint from the mural paintings of the interior dome and rotunda of the California State Capitol Building in Sacramento (see figure 8). A xenon flashlamp system was used to uncover 95 square meters of the surface and a ruby laser divested another square meter of detail. (That same year the flashlamp and laser systems were taken to the Long Beach Naval Shipyard in California to remove marine fouling and antifouling coatings from vessel hulls)

The next historic restoration project took place in 1980 in Dallas, Texas. The flashlamp system was used to remove corrosion from several hundred square meters of hundred-year-old steel trusses in the County Courthouse. The final large-scale project in this era (1981) was conducted at Arches National Park in Utah. Again, the flashlamp system was utilized (on a 200 meter cliff face) to selectively remove mineralization from portions of a 15 square meter Native American pictograph.

Figure 4. Manuscript cleaned by YAG harmonic (left) and excimer laser (center).

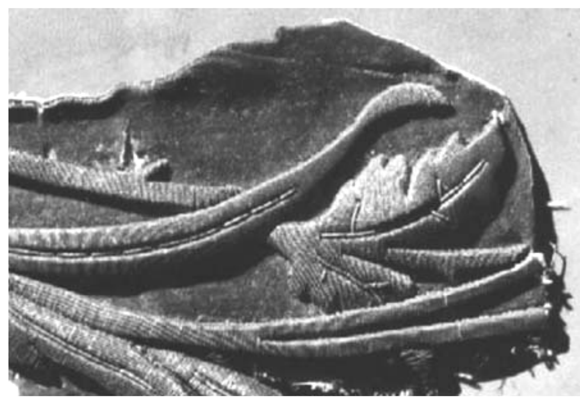
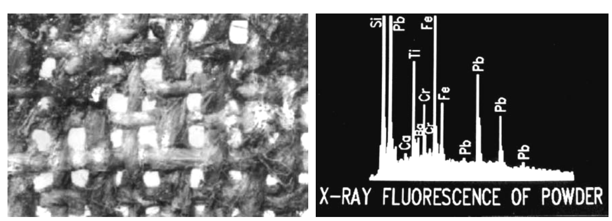


Figure 5. Cleaned silver threads (leaf, right) in Bavarian cloth.



Figures 6 and 7. Left: Hardened glue removed from Raphael-painting support canvas (center). Right: XRF analysis of paint-stripping debris.

The fieldwork described above demonstrated both the practical viability and the advantages of the radiation-divestment process. It also illuminated numerous problems with the equipment and the manner in which it was utilized. Fortunately, Burke's "Trigger Effect"[1] struck at this juncture with the dawning of the "Microprocessor

Age".

5 Current development

Throughout the 1960s and 1970s scores of highly touted industrial lasers, laser systems, and laser applications failed. Problems with reliability and maintenance were the factors cited most often in post-mortem examinations. The 1980s witnessed a dramatic turnaround in numerous fields (from medicine to semiconductor processing). Without a doubt, advances in materials and engineering played important roles in that revolution.

On the other hand the microprocessor is crucial to a great many of the modern laser-system success stories. It has become possible to achieve a high degree of real-time control of laser power and beam quality. Gas mixture and simmer control can extend life. Of comparable importance is microprocessor technology in process control through robotics, machine vision, real-time signal processing, and proximity sensors. This is not to say that laser automation will replace the human conservator in divestment procedures. To the contrary, it is evident from practical experience that automated process monitoring can greatly lessen operator fatigue, exposure to hazardous (non laser) light levels, and toxic vapors. This is especially the case when using high rep-rate and/or high-power lasers. Such automated control was found essential in the restoration of the Qin-Dynasty Terra Cotta Treasure Trove[26] (see figure 9).

Electronic spectral camera control can be used to vary scanning speed in order to avoid substrate melting. Similarly, it facilitates uniform coating removal in hard to reach areas such as the perimeter boundary of a rivet heads in steel bridge trusses. Figure 10 shows the automated industrial YAG laser system employed for lead-paint stripping tests[27]. This 3 kW laser system incorporates a long 100 m fiber-optic beam-delivery cable, a machine-vision spectral camera for process control, a gas-assist jet, and a debris-collection tube (all manipulated by a robot)[28].

6 Conclusions

During the past five years the advances in systems such as those described above have been explosive. In the present new millennium these will undergo refinements, costs will continue to drop, and wider ranges of performance will be offered by the manufacturers.

However, high-power semiconductor diode laser arrays (which have begun to appear in materials processing systems) will very likely revolutionize the field. Current advances in reducing costs, providing shorter wavelengths, interfacing with fiber-optic couplers, and increasing life at higher peak powers all bode well for the future and for eventual utilization in the field of art conservation.

Figures 8 and 9. Left: Flashlamp paint stripping Sacramento rotunda; Right: Restoring a Xi'an terra cotta warrior model.

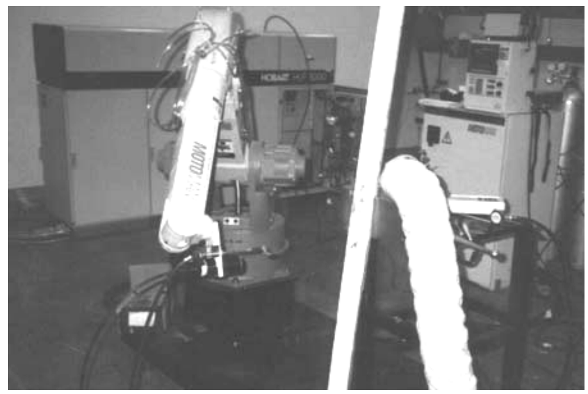


Figure 10. LIBS-automated robotic paint stripping system.

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