THE ERBIUM YAG LASER
History of Application to Fine Art Conservation

The concept of using lasers to remove encrustations from painted surfaces was developed in 1978 by Adele de Cruz while working at Stanford University in the Applied Physics Department. At that time, it was thought possible that pulsed energy might remove over-paint and cross-linked substances from the surface of an art work without doing damage to the substrate. However, it also was recognized that further development of the technology regarding the delivery of a laser pulse to the surface of an art work would be necessary before any conclusions could be reached. There then followed years of diligent study, calculation and experimental testing before tentative conclusions could be reached regarding the efficacy and safety of laser technology in the restoration of works of art.

In early 1994, Adele de Cruz presented to Professor Myron Wolbarsht, (a physicist at Duke University who was a pioneer in laser technology), her theory of using pulsed energy to remove over-paint and other foreign substances from the surface of works of art. In April, 1994 Professor Wolbarsht and de Cruz began a joint research project to determine what particular wavelength would enable the most efficient removal of cross-linked encrustation from an art work without affecting the integrity of the underlying painted surface. Under the guidance of Professor Wolbarsht various wavelengths in ultraviolet and infrared were tested. In the ultraviolet, an Argon Fluoride Excimer laser at 193nm was found to be effective in removing organic materials, such as natural resin varnish, but it was not effective when materials such as inorganic pigments were present in the layer to be removed. Conversely, testing of the Nd:YAG laser at 1064 nm revealed that it was effective in removing inorganic materials but it was not effective in removing organic materials. Also, the deep penetration of this layer by the laser pulse made it impossible to remove encrustations from painted surfaces without damage to the substrate.

In 1995, both the Erbium:YAG laser and the Hydrogen Fluoride laser were tested and at 3 microns each was found to be efficient in the removal of over- paint from the underlying delicate painted substrate without causing thermal damage to the paint surface. Because an apparently efficient, safe wavelength had been identified, a more detailed investigation was planned.

Also in 1995, experiments with the tuned Free Electron Laser were conducted at Duke University. When that laser was tuned to 3 microns in the mid-infrared at various pulse rates the results looked promising.Then, in December, 1995 Wolbarsht and de Cruz traveled to St. Petersburg. Russia to test a Hydrogen Fluoride laser. Hydrogen Fluoride laser. These experiments were done with using pulsed laser with the low energy of 50-100 Hz. which resulted in the successful removal of organic and inorganic encrustations without thermal or mechanical damage to the substrate.

However, the technology using the Hydrogen Fluoride laser was still experimental because the delivery system had not been adequately developed. Furthermore, the laser weighed 250 kilos – a fact that rendered it impractical for use at on-site locations for the conservation of art works.

Having determined that a pulsed laser at 3 microns depth was able to remove cross-lined encrustation and over-paint, it was understood that ablation of encrustation comprised of both organic and inorganic materials was possible because at 3 microns the wavelength is exclusively sensitive to the -OH molecule or water. The introduction of water, or any other –OH bearing solvent, enables the shallow ablation of 2-3 microns with confined thermal effects. The pulsed energy turns the water into steam (on a micro level) taking with it particles of the material that have been removed – all with a temperature not in excess of 100 degrees centigrade.

In 1996, research was begun with the Erbium:YAG crystal laser at the Free Electron Laboratory at Duke University where an effective means of delivering the pulsed laser energy to the art object was investigated. Various means of delivering the pulsed energy laser were tested and it was determined that a hollow glass tube (developed at Rutgers University) was an effective means of delivering the laser energy to the surface of the art work.

On April 1, 1997, the successful delivery of the pulse energy of the Erbium:YAG laser enabled the removal of encrustation from the delicate painted surface of an art work, whereas removal of those same encrustations using a solvent failed completely. At that time, Schwartz Electro Optics Company in Orlando, Florida recognized the effectiveness of the Erbium:YAG laser. Subsequently, under the direction of an accomplished laser engineer, Ed Adamkiewicz, the Erbium: YAG laser for Fine Art Conservation was developed and that unit was the prototype for our current portable laser that weighs only 35 lbs.

Subsequently, research regarding the efficiency and safety features of the Erbium: YAG laser continued with the assistance of Dr. Richard Palmer of the Duke University Chemistry Department. FTIR and ATR examination of material ablated from the surface of an art work determined that no micro-particles of color from the substrate had been ablated during the process, i.e. only the foreign material (encrustations) had been removed.

The several years of careful, tedious work required to perfect the Erbium: YAG laser culminated in the presentation of a paper entitled "The Chemistry of Color" at the International Conference on the Chemistry of Color held at the Louvre in September, 1998.

In May, 1999 de Cruz and Wolbarcht presented another paper entitled "The Method for Cleaning Art Works" at the meeting of the Northeastern Association of Conservators held at the Metropolitan Museum of Art. This paper focused on a description of the results obtained following the use of the Erbium:YAG laser in art conservation.

In July, 1999, a joint research project regarding the use of the Erbium:YAG laser at 3 microns for art restoration was undertaken by the Opificio delle Pietre Dure (Florence, Italy), the University of Pisa, Duke University and SEO (Schwartz Electro Optics). The combined results of that project were presented on May 9, 2001 at an International Workshop in Florence, Italy. At that time, it was reported that chemical tests of FTIR, gas Chromatography, Electron Scanning Microscopy and cross-section micro analysis found no chemical or physical changes to the paint sustrate caused by laser radiation.

By June 2001 research at the Vatican Conservation Laboratory in Rome, involving the Erbium YAG laser had expanded to include other forms of art work conservation including fresco, tapestry, bronze and stone sculpture.

On September 12, 2001 the result of the research to date, using the Erbium:YAG Laser to conserve works of art was presented at the International Conference of LACONA IV held at the Louvre.

In January 2002, with a grant from the Banco di Respairo of Florence, a joint research project at the Opificio delle Pietre Dure in Florence, the University of Pisa and Duke University was expanded to include fresco, paper and textile conservation.

Also in January 2002 a research program on polychrome sculpture (marble and limestone) began at the Duke University Art Museum. This research was conducted in conjunction with the Chemistry Department at Duke University where Professor Palmer and de Cruz co-directed students in the project. The result of this work was presented at the LaconaV International Conference in Osnabrueck, Germany in October, 2003. It reported the results following the cleaning of 4 sculptures with a pulsed Erbium:YAG laser. The objects included (1) the removal of lichen from a 13th century sandstone head; (2) the removal of cross-linked egg white from a 14th century polychrome head; (3) the removal of calcite from a 2nd century Roman entablature; and, (4) the removal of gypsum from a 15th century polychrome marble relief. Following the completion of the cleaning, the results, evaluated by FTIR, ATR and x-ray, indicated that the Erbium:YAG laser was effective in removing organic and inoganic materials from the surface of a sculpture without causing chemical or physical changes to the surface of the art work. These findings were presented by a student of Professor Palmer and de Cruz, named Sarah Pierce, at an international conference of IRFTIR analysis held in Florence in March, 2004.

In June, 2004, the collected findings of the use of the Erbium:YAG laser for art conservation were presented at the American Institute of Conservation Conference in Portland, Oregon.

In early 2005, joint research programs using the Erbium:YAG laser began at the Philadelphia Museum, the Metropolitan Museum, the New York State Center of Conservation, Peebles Island and at the Center for National Research in Florence and Milan, Italy.

In 2005, The Vatican Museum Conservation Laboratory purchased an Erbium:YAG laser from *MonaLaser*, the American company that offers these instruments for sale. The Opificio della Pietre Dure in Florence has also been using an Erbium:YAG laser on loan from MonaLaser.

Professor Palmer and Ms. de Cruz are presently engaged in the study of the removal of lichen from the surface of 13th and 14th century limestone and marble objects.

Additional presentations of the results of ongoing research projects regarding the use of the Erbium:YAG laser were presented at the International Conference on the Microbiology and Conservation of Cultural Heritage in Portsmouth, England in June, 2005 and at the LACONA VI International Conference in Vienna, Austria in September, 2005.

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