SCIENTIFIC AND TECHNICAL CONFERENCE
LASER TECHNOLOGIES. LASERS AND THEIR APPLICATION
LTLA-2025

Microscopic and Spectroscopic Analysis of Laser Light Effects in Paint Layers

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Abstract: This study presents an analysis of structural and electronic changes in a layer of paint applied to a glass substrate, induced by laser light exposure. Initially, the sample was examined using Scanning Electron Microscopy (SEM) and Electron Magnetic Resonance (EMR) spectroscopy to determine its initial surface morphology and electronic properties [1]. The sample was then divided into two parts: one was irradiated with a red helium-neon (He-Ne) laser, and the other with a green diode laser. Following the irradiation, both parts were reanalyzed using SEM and EMR techniques [2]. The results revealed changes in surface structure and the presence of magnetic centers, depending on the type of laser radiation used. The conducted research provides valuable insights into the impact of laser light on the physicochemical properties of paint layers and may be applicable in the field of material diagnostics.

SEM (Scanning Electron Microscope)

The FEI Quanta 3D 200i is an advanced scanning electron microscope (SEM) equipped with an Energy Dispersive Spectroscopy (EDS) chemical analyzer, enabling detailed examination of surface structure, internal composition, and chemical makeup of samples. The microscope operates under high vacuum conditions and supports an accelerating voltage of up to 10 kV, allowing for precise chemical analysis of materials.

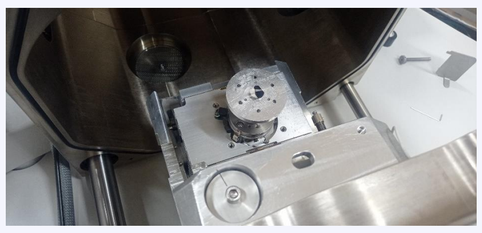

Figure 1. Scanning electron microscope (SEM) FEI Quanta 3D 200i with EDS Analyzer

With the use of a secondary electron (SE) detector, the microscope provides high-quality microscopic images of the examined samples. It offers magnification in the range of 109× to 120×, making it an ideal tool for analyzing paint coatings, pigments, and various engineering materials.

EMR (Electron Magnetic Resonance)

Application of EMR Spectroscopy for the Analysis of Paints After Laser Exposure
Electron Magnetic Resonance (EMR) spectroscopy is a highly sensitive technique that enables detection and analysis of magnetic centers such as free radicals and transition metal ions. It is especially useful in studying **the effects of laser irradiation on coating materials**, as laser exposure can induce photodegradation, bond scission, and the formation of reactive radical species [1,2].
EMR is uniquely suited to:

- **Detect laser-induced radicals** within pigment structures or polymeric binders [2,3],
- **Track changes in oxidation states** and degradation pathways under high-energy light exposure [3],
- **Characterize molecular changes** on the microstructural level, even in complex materials such as technical paints used in aerospace or space applications [1],
- Provide **non-destructive, precise insights into chemical composition** and photostability of pigment systems [2].

The technique complements laser photolysis and spin-trapping studies, offering unique advantages in understanding the stability and aging of high-performance coatings under simulated or real radiation environments [3].

Research

The Investigated Paint – Black

Synthetic paint based on alkyd resins containing corrosion inhibitors
Chemical composition:

- **Base:** Alkyd resin
- **Solvents:** Odorless aliphatic solvents
- **Pigments:** Iron oxides, titanium dioxide, organic and inorganic pigments
- **Additives:** Thixotropic agents, anti-corrosion agents, drying accelerators
  - Hydrocarbons C9–C11: n-alkanes, isoalkanes, cyclics, <2% aromatics
  - Zinc phosphate dihydrate
  - n-Butyl alcohol
  - Zirconium 2-ethylhexanoate
  - Cobalt neodecanoate

Diode laser pointer (λ = 532 nm, P < 5 mW, green, USB-powered), used for sample irradiation

Figure 2. Setup for paint irradiation using a laser diode

Experimental setup with a He-Ne laser (λ = 632.8 nm, P = 1 mW) for irradiation of the black paint sample

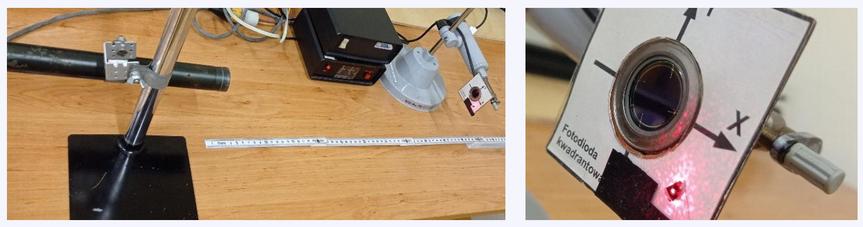

Figure 3. Setup for paint irradiation using a He-Ne laser

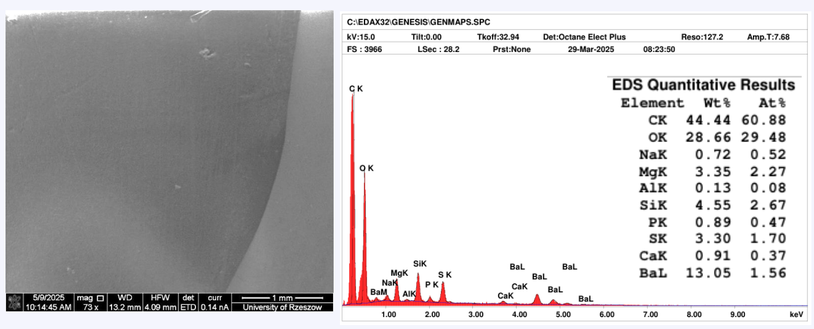

Figure 4. SEM image of the investigated black paint

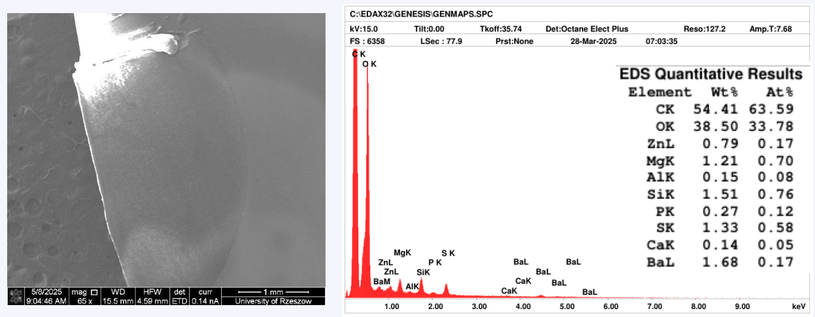

Figure 5. SEM image of black paint after exposure to green laser diode

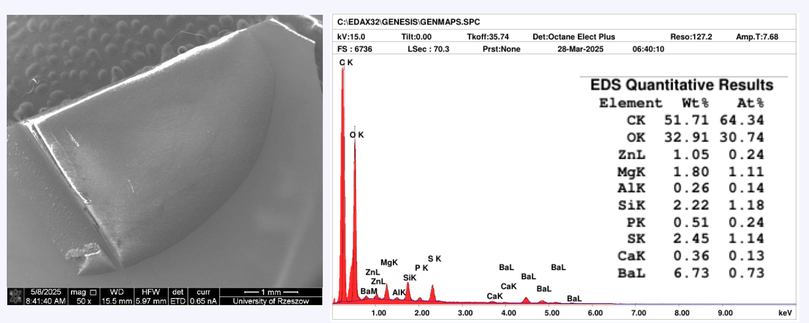

Figure 6. SEM image of black paint after exposure to He-Ne laser

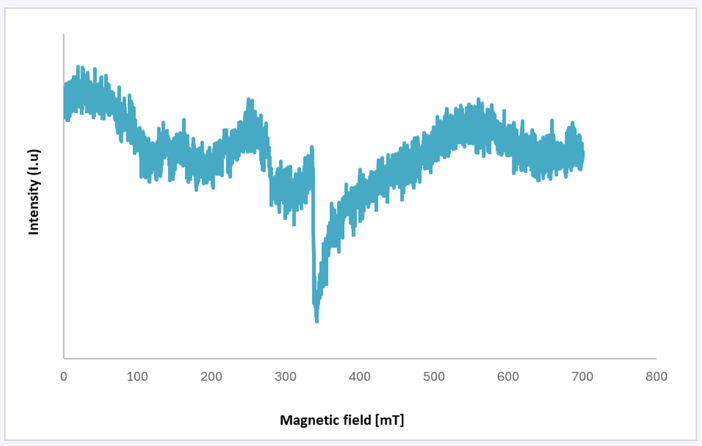

Figure 7.EMR spectrum of the investigated black paint sample without laser exposure

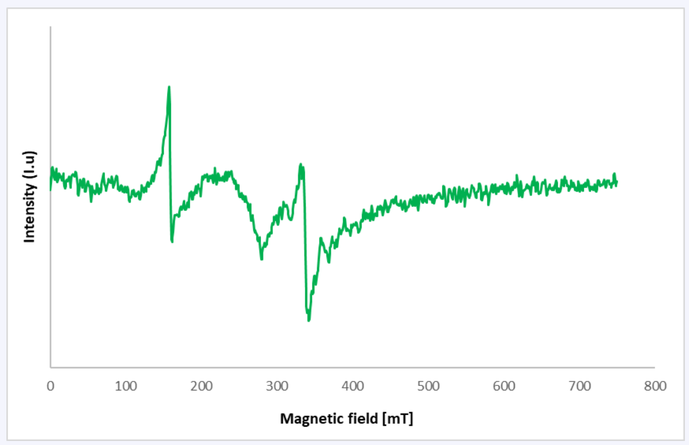

Figure 8. EMR spectrum of the investigated black paint sample after diode laser pointer exposure

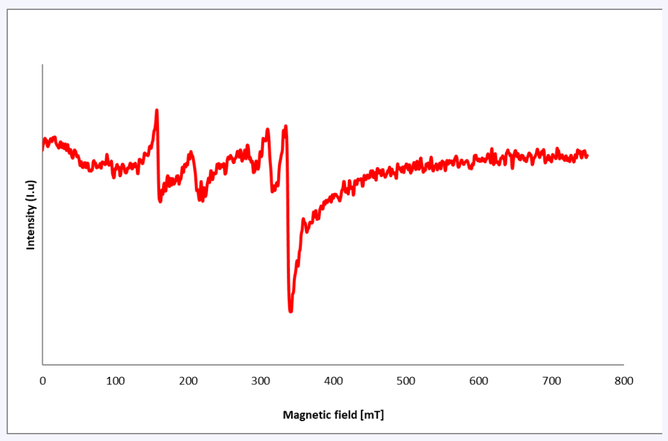

Figure 9. EMR spectrum of the investigated black paint sample after He-Ne laser exposure

Conclusions

The conducted research demonstrated that laser irradiation significantly affects the physicochemical properties of synthetic paint layers based on alkyd resins. Scanning Electron Microscopy (SEM) revealed distinct changes in the surface morphology of the black paint samples after exposure to both a He-Ne laser and a green laser diode. These changes included the appearance of microcracks, surface roughness, and localized structural damage. Electron Magnetic Resonance (EMR) spectroscopy confirmed the formation of new magnetic centers, including free radicals, which were not present in the non-irradiated samples. This indicates that photochemical reactions are induced within the pigment and binder structures due to laser light exposure. The most pronounced effects were observed following irradiation with the He-Ne laser, suggesting that red light at 632.8 nm and 1 mW power can more effectively initiate chemical degradation than green light (532 nm) from a laser diode with <5 mW power. These findings confirm that SEM and EMR techniques provide a complementary and effective approach for analyzing laser-induced changes in paint coatings. The results may have practical implications for evaluating the durability and stability of technical coatings exposed to laser light, particularly in industrial and aerospace applications.

Literatura

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