

# Colorizing Metals with Femtosecond Laser Pulses

A.Y. Vorobyev and Chunlei Guo

For centuries, alchemists have dreamed about turning base metals into gold. Certainly, it is not enough from an alchemist's point of view to transfer only the appearance of a base metal to gold. However, the possibility of rendering a metal to a completely different color without coating can be interesting in its own right. By treating metal surfaces with intense femtosecond laser pulses, we demonstrated that we can transform metals into different colors.<sup>1</sup>

To colorize metals, we used a femtosecond Ti:sapphire laser that generates pulses of about 1.1 mJ/pulse with a central wavelength at 800 nm. A large area of metal was colorized by scanning the femtosecond laser beam across the metal surface. The metals we studied include aluminum, gold, titanium and platinum. To produce a certain color, we carefully chose a set of laser processing conditions. As shown in part (a) of the figure, we transformed a piece of shiny aluminum into a golden appearance. To examine what is responsible for metal coloring, we also performed a scanning electron microscope (SEM) study. SEM images reveal that the surface of the gold aluminum is predominantly covered by nanostructures in the form of nanoprotuberances and nanovoids.

To understand why aluminum appears to be gold, we characterized the spectral responsivity of the gold aluminum and untreated aluminum by measuring the wavelength dependence of the total reflectance in the ultraviolet, visible and infrared regions (250 nm to 2.5  $\mu\text{m}$ ), as shown in (c). We noticed that the reflectance of the gold aluminum drops over the entire measured wavelength range compared to the untreated aluminum. The decline in reflectance, however, was more

pronounced as wavelength decreased: The reflectance was about 65 percent at 2.5  $\mu\text{m}$  but nearly vanished at 250 nm.

This spectral dependence caused a greater absorption at the blue and green wavelength range, leading to a golden color. Other colors can also be produced when experimental conditions are modified. All the colored metals discussed here exhibited the same color under various viewing angles. In our study, we also produced black and gray aluminum. The black aluminum is shown in part (b) of the figure. The reflectance of the black aluminum approaches zero over the entire wavelength range measured.

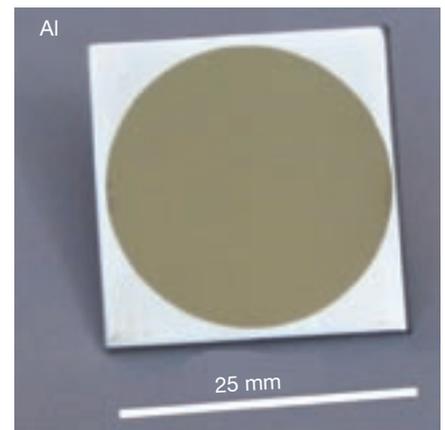
To perform the spectral dependence measurements, we processed a relatively large blackened area and optimized the experimental condition for maximum blackness by visual examination. We believe that the remaining few percent of reflectance can be suppressed by further optimizing the processing conditions.

In summary, we have demonstrated, both visually and through spectral measurements, the creation of colored metals with a femtosecond laser surface structuring technique. Our technique essentially provides a controllable modification of optical properties of metals from ultraviolet to infrared. Giving the additional advantages of laser processing, such as low contamination and the capability to process complicated shapes, the colored metals have tremendous potential in various technological applications. ▲

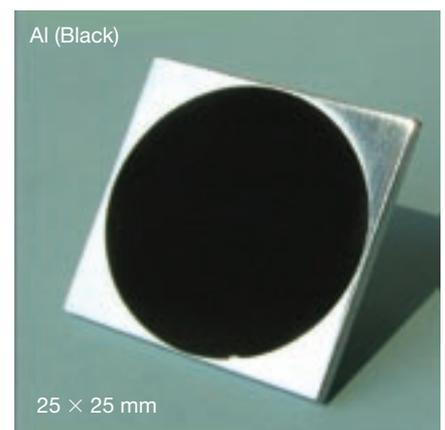
A.Y. Vorobyev and Chunlei Guo (guo@optics.rochester.edu) are with the Institute of Optics, University of Rochester, Rochester, N.Y., U.S.A.

#### References

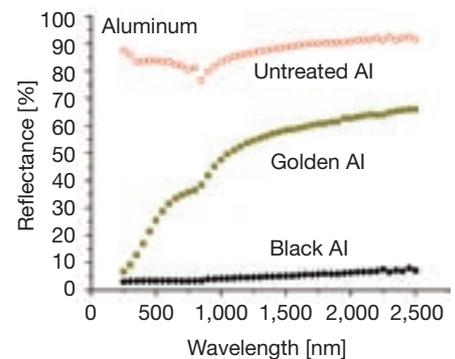
1. A.Y. Vorobyev and C. Guo. *Appl. Phys. Lett.* **92**, 041914 (2008).



(a)



(b)



(c)

(a) Gold aluminum; (b) black aluminum; and (c) wavelength-dependent reflectance of untreated gold and black aluminum.