strong coupling between stripes persists at high drives. By observing whether a maximum is shifted from the facet normal, some idea of the phase shift between stripe may be obtained, which further indicates whether odd or even modes are propagating in the passive waveguides. Little overall contribution is made by the stripe regions, however, as they occupy only about 15% of the total emitting area of the device.

In conclusion, we have successfully developed a new multiple-stripe laser structure that utilizes leaky-mode coupling to produce stable outputs to peak powers of 1.5 W. The advantages of the device are "kink-free" operation and a significant enhancement of the critical threshold for catastrophic mirror damage. Operation with even more stripes should be possible because of the strength of the leaky-mode coupling, and the far-field pattern may be modified for specific applications by adjusting $\Delta n$. These devices are promising for applications that require stable output characteristics at high peak powers.

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**Graded-index Pt-Al$_2$O$_3$ composite solar absorbers**

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The solar absorption properties of thin composite films of coevaporated Pt and Al$_2$O$_3$, formed with a graded composition-depth profile, are compared to those of an identical film overcoated with a microscopically textured layer of SiO$_2$. The composition grade of the metal-dielectric composite and the surface texturing of the SiO$_2$ produces a film with a refractive index slowly varying to unity at the front surface. This results in a very low reflectance of the film. The solar absorptivity of this graded refractive index surface is shown to be as high as 0.98. The production and structure of these surfaces are described as well as a general method of absorptivity enhancement using a microscopically textured surface formed by reactive ion etching.

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Within the class of materials considered as candidates for solar photothermal absorbers the metal-dielectric composites are useful for high-temperature, high-efficiency applications. These composite films, when prepared in a finely divided dielectric-rich form, strongly absorb radiation over much of the solar spectrum but remain transparent to longer wavelength radiation. By depositing such a composite film on a low-emissivity metal surface a spectrally selective absorbing surface is produced. The selective surface efficiently absorbs the solar radiation and loses little energy by reradiation. The figures of merit describing a solar selective absorber are $\alpha$, the fraction of solar flux absorbed, and the emissivity $\epsilon(T)$, the thermal emittance relative to a blackbody at temperature $T$. For the case of a solar concentrating...
collector system with a large concentration factor of the solar flux, the total system efficiency is nearly proportional to \( \alpha \). In this case a large \( \alpha \) is desirable even at the expense of an increased \( \epsilon \). In this letter we describe an ultrahigh absorptivity selective absorber based on a Pt-Al\(_2\)O\(_3\) composite with a graded refractive-index depth profile. The graded composite film gives a refractive index, which varies smoothly from that of Pt to that of aluminum oxide \((\sim 1.65)\). The graded-index, combined with the absorbing nature of the composite material, produces a very low reflectance and thus highly absorbing surface.\(^4\)\(^5\) To grade the index further from \( \sim 1.65 \) to unity, the novel technique of texturing a dielectric surface has been employed. By creating submicron sized conical surface structures, an effective medium of air and dielectric is created with a spatially varying refractive index.

The Pt-Al\(_2\)O\(_3\) composite film was produced by coevaporation of Pt and Al\(_2\)O\(_3\) from independently controlled electron-beam sources.\(^6\) A layer of Pt, \( \sim 1000 \) A thick, was deposited on a heated quartz substrate. This was followed immediately by coevaporation of Pt and Al\(_2\)O\(_3\) with the relative deposition rates varying continuously from 100\% Pt and 0\% Al\(_2\)O\(_3\) initially to 0\% Pt and 100\% Al\(_2\)O\(_3\), finally. The result was a composite film \( \sim 4000 \) A thick with the Pt content varying nearly linearly with depth into the film. In a second vacuum system a 4000-A-thick layer of SiO\(_2\) was deposited on top of the Pt-Al\(_2\)O\(_3\) composite by electron beam deposition from an SiO\(_2\) source. The oxide layer is denoted as SiO\(_2\), since the evaporation of SiO\(_2\) at a pressure of \( \sim 1 \times 10^{-7} \) Torr is known to produce oxygen-deficient films. Immediately following this a layer of Al. 250-A average thickness, was deposited on the sample surface while it was maintained at a temperature of 300 °C. At this thickness and temperature the Al forms an island film which sets the scale of granularity that is ultimately transferred into a surface texture by reactive ion etching.

The reactive etching of the samples was carried out on the cathode of a conventional diode sputtering station. The SiO\(_2\) was etched with a plasma of the gas CF\(_4\). A total power density of 0.5 W/cm\(^2\), a gas pressure of 20 mTorr, and a cathode self-bias of 500 V were used. While this plasma forms volatile reaction products with the silicon oxide, the Al island masks are eroded much more slowly. The result of this anisotropic etching is the formation of conical structures

![Schematic cross-sectional view of a graded composition Pt-Al\(_2\)O\(_3\), composite film coated with a textured surface layer of SiO\(_2\).](image1)

![Schematic cross-sectional view of a graded composition Pt-Al\(_2\)O\(_3\), composite film coated with a textured surface layer of SiO\(_2\).](image2)

FIG. 1. Schematic cross-sectional view of a graded composition Pt-Al\(_2\)O\(_3\), composite film coated with a textured surface layer of SiO\(_2\).
UNCOATED Pt-Al$_2$O$_3$
\[\alpha = 0.94\]

SiO$_x$ COATED Pt-Al$_2$O$_3$
\[\alpha = 0.98\]

WAVELENGTH (\mu m)

Reflectance

FIG. 3. Measured specular reflectance of a graded composition Pt-Al$_2$O$_3$ composite solar absorber (solid curve) and the reflectance for the same composite film coated with a graded index textured layer of SiO$_x$. From these curves the solar absorptivities of the uncoated and SiO$_x$ coated composite are 0.94 and 0.98, respectively.

The microscopic surface morphology formed on an evaporated SiO$_x$ layer is shown in the scanning electron micrographs of Fig. 2. The sample, coated with $\sim$200 Å of gold to improve the image contrast and prevent charging, is viewed at normal incidence and at an angle of 45°. The surface consists of irregular cones with an average height of $\sim$0.3 \mu m. A slightly higher cone structure would be beneficial in providing a more gradual refractive index change for wavelengths $\simeq$ 1 \mu m. However, this observed scale of surface structure has effectively reduced the surface reflection within the wavelength range of the maximum solar flux, yielding a substantial increase in the solar absorptivity.

The near normal specular reflectances $R(\lambda)$ of Pt-Al$_2$O$_3$ composite film and the same film coated with textured SiO$_x$, measured over a wavelength range of 0.25-14.0 \mu m, are shown in Fig. 3. The dashed curve in this figure represents the compositionally graded but uncoated Pt-Al$_2$O$_3$ composite film. One observes here a low reflectance for wavelengths $\leq$ 3.0 \mu m with noticeable oscillations due to thin-film interference effects and a rapid increase in the reflectance for wavelengths $> 3.0 \mu m$. From this curve $\alpha$ was calculated using

$$\alpha = \int [1 - R(\lambda)]S(\lambda) d\lambda,$$

where $S(\lambda)$ is the solar spectrum, giving $\alpha = 0.94$. The solid curve in Fig. 3 displaying $R(\lambda)$ for the textured SiO$_x$-coated composite is significantly lower than that for the uncoated film over the 0.25-2.0-\mu m wavelength range giving $\alpha = 0.98$. There is a noticeable dip in the reflectance of the coated sample at $\sim 9.5 \mu m$ due to an absorption peak in the SiO$_x$. Because of the decrease in the reflectance for the coated film the emissivity of the SiO$_x$-coated absorber is greater. The thermal emissivity is 0.21 and 0.36 for the uncoated and SiO$_x$-coated films, respectively, as estimated at 200 °C from the relation

$$\epsilon = \int [1 - R(\lambda)]/U(\lambda,T) d\lambda;$$

where $U(\lambda,T)$ is the Planck spectral distribution function at temperature $T$.

This specific Pt-Al$_2$O$_3$ was produced rather thick to maximize the absorptivity at the cost of increased emissivity. Other thicknesses can be produced to give the best possible $\alpha$ and $\epsilon$ values for a given application. Because of the reflectance of the Al$_2$O$_3$-air interface, $\alpha = 0.94$ is approximately the upper limit of the solar absorptivity that can be achieved by grading the Pt concentration in the composite film. By the addition of a textured SiO$_x$ antireflection layer we have increased the solar absorptivity above this limit to 0.98. By the formation of thicker layers of both the composite and SiO$_x$, absorptivities arbitrarily close to unity can be obtained. This graded-index surface of silicon oxide does not require the formation of a tuned optical system, as would a multilayer interference film, and can be formed easily over large areas. The coating is also effective for all wavelengths which would be unachievable by any other simple technique. The etched dielectric coating, index-matching technique can be applied to any transparent etchable material to reduce the reflectance. We have described a method to produce ultrahigh absorptivity solar absorbing coatings by creating a film with a refractive index smoothly graded to the value of air.

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3A. J. Sievers, in Ref. 2.