of a ray in a whispering gallery mode to fluctuate in time. Eventually a ray trapped by total internal reflection impinges on the boundary below the critical angle and escapes by refraction.

However, at higher deformations (*i.e.*, above ~10%) a different type of laser resonance emerges and is responsible for highly directional (~45° off the major axis, see Fig. 1) and high-power emission. Unlike the chaotic whispering gallery modes of smaller deformations, these bow-tie resonances are stable resonator modes surrounded on all sides (in phase space) by chaotic motion. Their modal path and emission pattern is shown in the right inset to Figure 1. In the favorable directions of the far-field, the "bow-tie" laser shows a power increase of up to three orders of magnitude over the conventional circularly symmetric laser. A peak output power of 10 mW (one quadrant) is measured for a laser with minor and major axis diameters of 40- and 60-μm, respectively, waveguide thickness 5.4 μm, at 100 K heat sink temperature. The lasers are operated in pulsed mode and show laser action up to 270 K.

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Coupled Microcavities in Light-Emitting Porous Silicon

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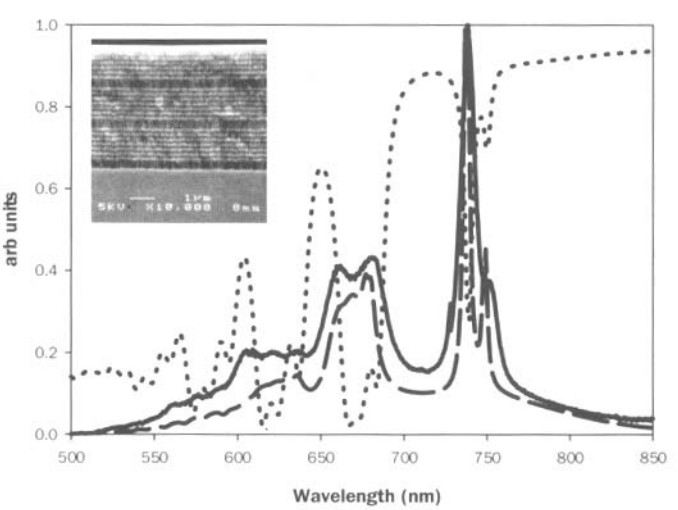
Although porous silicon (p-Si) can be easily, rapidly, and cheaply produced in electrochemical cells without the need for lithographic or epitaxial techniques, the emitted light has an undesirably broad spectrum (FWHM ~150 nm) and long (microsecond) decay times.[1] If the spectrum can be narrowed, the response time reduced, and the efficiency improved, p-Si light emitters are likely to rapidly find their way into advanced Si-based optoelectronic chips. A potential way of overcoming these limitations is to place the p-Si in a resonant environment—but how best to produce a high quality micro-resonator? An attractive feature of the anodic etching process is that the porosity is a strong and reproducible function of current density. This means that multilayer stacks with precisely controlled refractive index profiles can be produced. This has been used to produce passive filters and microcavities that enhance the p-Si luminescence.[2,3]

We have produced a range of multilayer structures in p-Si and for the first time successfully modeled their emission spectra using only the macroscopic optical properties of the layers (refractive index, absorption coefficient, layer thickness, emission spectrum) without detailed knowledge of their microscopic physical and electronic structure. Figure 1 shows the intricate optical properties of a 42-layer porous silicon coupled-microcavity system. The sample (SEM inset) consists of two cavities bounded by 13-layer mirrors comprised of 0.11-μm (41% porosity) and 0.08-μm (69% porosity) layers. The figure shows the measured reflectivity and photoluminescence spectrum—both strongly modified compared to a bulk porous silicon layer. As expected, the luminescence peaks at the transmission maxima for the unpumped structure (*i.e.*, at the reflectivity minima). The cavity modes at 740 nm dominate and are narrower than the first transmission mode on the low-wavelength side of the stop-band. Both the reflectivity and the emission spectrum show mode splitting arising from the coupling of the microcavities. Clearly, the emission has been enhanced and channeled into a few modes of the structure.

The emission spectrum is modeled using a modified transfer matrix technique, which includes the effect of porosity on the complex refractive index.[4] Emission effects are included using a gain spectrum derived from bulk emission properties. The results of the calculation closely match the details of the measured spectrum, illustrating the power of the approach.[5]

In summary, high performance multilayer microcavities can be produced rapidly in porous silicon with great precision and reproducibility. These structures considerably enhance the light emission from p-Si, allowing narrower bandwidths, higher efficiencies, and faster modulation rates, as well as making possible a wide range of useful passive devices.



Snow Figure 1. Spectra from a porous silicon 42-layer coupled microcavity system. The dotted spectrum is the sample reflectivity. The solid line shows the measured photoluminescence spectra after excitation by a 488-nm pump beam. The long-dashed line shows the modeled emission spectrum assuming constant excitation of all luminescent p-Si in the structure.

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NONLINEAR OPTICS

Laser Field Enhancement at the Scanning Tunneling Microscope Junction Measured by Optical Rectification

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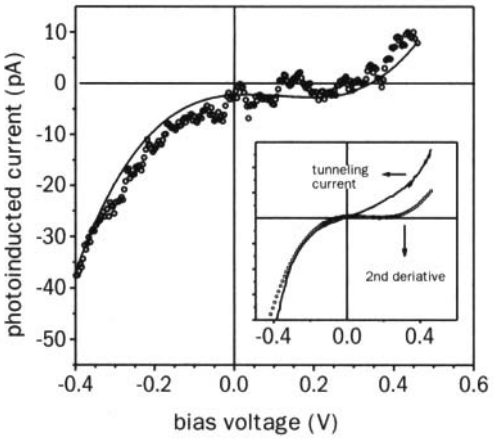
Optical field enhancement due to resonances in nanostructures is a well known phenomenon that has given rise to the development of techniques such as surface enhanced Raman spectroscopy[1] and surface modifications in the nanometric range, among others.[2] Many theoretical works[3] have predicted enhancement factors strongly dependent on the shape of the structure and the optical properties of the nanostructured material, magnitudes that are poorly known.

In a recent letter, we have been able to perform the direct measurement of the magnitude of the field enhancement by means of determining the rectified current induced at the tip of a scanning tunneling microscope (STM) junction.[4] The sharp metallic tip of the microscope acts as the enhancement structure, creating a very small region of a strong electric field. When the sample is brought to the tip, the enhanced field biases the tip-sample junction at the optical frequency giving rise to an electrical current. The nonlinear current-voltage response of the STM junction yields a term proportional to the electric field squared (optical rectification), which has a net DC contribution that can be measured with the instrument amplifier. The simultaneous measurement of both the DC bias current and the optical rectified contribution allows the determination of the voltage drop induced by the optical field across the tip-sample region. In Figure 1, the optically induced current is shown as a function of the biasing voltage, and fitted (solid line) with the second derivative of the DC current. Thermal effects due to the expansion of the sample heated by the laser were also considered.[5] As a guide, the inset in the figure shows the measured DC current and its calculated second derivative. The value of the enhanced field can be extracted from our knowledge of the tip sample distance. The magnitude of the field enhancement achieved for the particular case of the figure is 450, and depends on the particular tip used. Similar values are obtained for highly oriented pyrollitic graphite, indicating that the enhancement is mainly due to the tip.



Bragas Figure 1. Photoinduced tunneling current as a function of the STM tip-sample biasing voltage. Dots are measured values and the full line is the fit corresponding to the optical rectification contribution. The inset shows the DC contribution and its second derivative used to fit the data.

This large field enhancement in a very confined region should find applications in diverse fields such as surface nanomodification, particle trapping, field enhanced optical microscopy, nanoscaled nonlinear optics, and testing models for the linear and nonlinear optical response of nanostructures. The possibility of measuring a particular field enhancement for a given structure is a relevant step toward the mentioned applications.

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Suppression of Multiphoton Fluorescence in Hyper-Rayleigh Scattering

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Hyper-Rayleigh scattering (HRS) has become widely accepted as an experimental technique for the determination of the first hyperpolarizability (second-order nonlinear polarizability), β, of molecules in solution. Apart from being simpler both theoretically and experimentally than electric-field-induced second-harmonic generation (EFISHG)—applicable to neutral, dipolar molecules only—HRS is the sole technique that gives a β value for ionic or octopolar species. The combination of HRS and EFISHG also allows different elements of the hyperpolarizability tensor to be analyzed.

However, because of the incoherent nature of HRS, no discrimination is possible against multiphoton fluorescence at exactly the second-harmonic wavelength. We have now implemented a technique that does just that, enabling the measurement of ionic or octopolar, as well as fluorescent species.