

## Highlighting an Interesting Parallel between Quantum Electronics and Quantum Photonics

### To the Editor:

Unfortunately, during production of the cover of the May 2003 issue of *MRS Bulletin* on Photonic Materials for Optical Communications, a wrong scale was included in the right-hand-side electron micrograph at the bottom. This destroyed the methodology behind the bordering scanning electron micrographs (SEMs) selected to point out a very interesting parallel between quantum electronics and quantum photonics. Figure 1 shows the set of images with the correct scale for each.

To tailor electronic energy levels for electrons and holes, semiconductor heterostructures of distinct layer thicknesses are designed, epitaxially grown, and applied in modern optoelectronic devices. If the layer thickness of the lower bandgap material is on the order of the *electron wavelength*, quantization occurs, leading to distinct quantized energy levels in the so-called quantum wells. These energy levels and the corresponding *electronic wavefunctions (modes)* are described by the *Schrödinger equation*. The materials, strain, and—dominantly important—the layer thicknesses in the 10 AlGaInAs multiple quantum wells (bottom left image in Figure 1) are tailored to generate light of about 1.55  $\mu\text{m}$  wavelength (gain profile).

These wells act as the laser active medium in the high-speed laser shown (top left image in Figure 1).<sup>1–3</sup> In a very simplified picture, the arrangement of the quantum wells define a *resonator for electron waves*.

The micrographs on the right-hand side in Figure 1 show the exact analogy for photons. In order to select a distinct mode in the resonator of a vertical-cavity surface emitting laser (VCSEL), layers having thicknesses on the order of the *photon wavelength* are chosen. In this case also, a kind of quantization takes place. The effective indices and the corresponding *photon wavefunctions (modes)* are described by the *Helmholtz equation* (from a mathematical point of view, the Schrödinger and Helmholtz equations are very similar). The example shows ultrahigh refractive-index contrast in InP/air-gap multiple membrane structures to define distributed Bragg reflectors of very high reflectance (here, for light in the wavelength range of 1.55  $\mu\text{m}$ ).<sup>4–6</sup> In a very simplified picture, the arrangement of the periodic refractive index variations define a *resonator for photon waves*.

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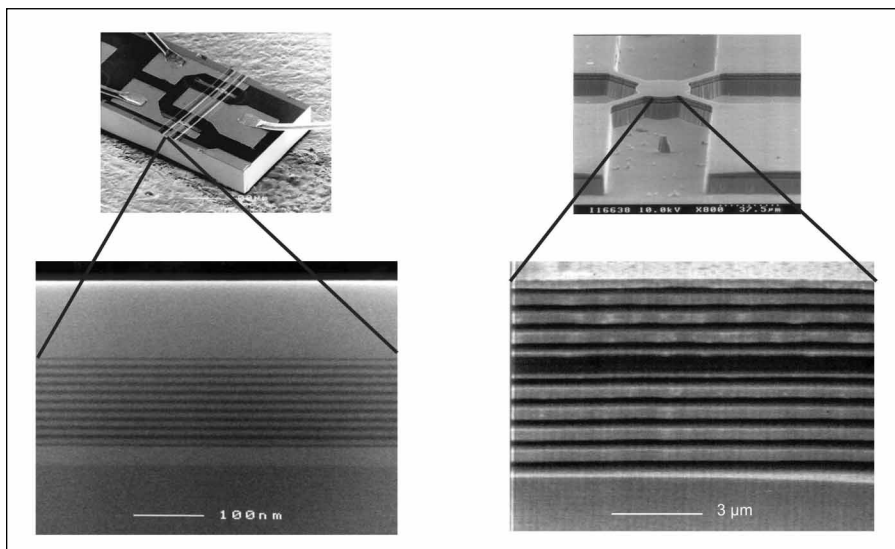


Figure 1. (left, top) Scanning electron microscopy (SEM) image of a tunable three-section bent-waveguide chirped distributed-feedback (DFB) grating edge-emitting 1.55  $\mu\text{m}$  AlGaInAs/InP laser. (left, bottom) Closer view of the active layers: 10 strain-compensated multiple quantum wells (MQWs) with tensile-strained AlGaInAs barriers and compressively strained AlGaInAs wells. (right, top) SEM image of a surface-micromachined 1.55  $\mu\text{m}$  GaInAsP vertical-cavity surface-emitting laser (VCSEL) composed of multiple membranes, each positioned by four suspensions connected to square supporting posts. (right, bottom) Closer view of the vertical resonator, consisting of a centered GaInAsP multiple-quantum-well laser active region embedded with two distributed Bragg reflector (DBR) mirrors consisting of (Ga)In(As)P/air-gap periods. The structure at the bottom left represents an electron wave resonator; the structure at the bottom right represents a photon wave resonator.

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