by an HCl transport process.[3] However, because of the reactivity of AlAs in air, these devices require an anodic oxide coating to improve the stability of the AlAs window.

We report here the first successful growth of GaAlAs/GaAs heterostructure solar cell materials by a vapor phase process, i.e., the chemical vapor deposition (CVD) of GaAlAs and GaAs employing metalorganic and hydride sources. Although metalorganic CVD (MO-CVD) has been used to grow films of GaAs,[4-6] AlAs,[7] and GaAlAs,[7] and portions of GaAlAs/GaAs heterostructure devices,[8] no results on the performance of heterostructure devices fabricated entirely in MO-DVD materials have been reported. Our results clearly demonstrate the suitability of this materials-growth technique to the production of high-quality, large-area, GaAlAs/GaAs heterostructures. These results thus have broad implications in the growth of other heterostructure devices such as LED's and injection lasers in addition to large-area GaAlAs/GaAs solar cells.

We have obtained simulated air-mass-zero (AM0)[9] open-circuit voltages up to 0.99 V, short circuit current densities of 24.5 mA/cm^2, and fill factors as high as 0.74 for devices without AR coatings. The highest AMO efficiency we have measured to date for devices with no AR coatings is 12.8% uncorrected for contact area (~10% coverage) and reflection losses.

The materials employed in the fabrication of these devices are 3-layer epitaxial structures of GaAlAs:Zn/GaAs:Zn/GaAs:Se grown entirely by MO-CVD on a (100)-oriented GaAs:Si substrate. Se-doping is provided by the addition of H_2Se gas to the reactor flow while Zn doping is accomplished by the use of diethyl-zinc (DEZn).[10,11] Typical layer thicknesses are: GaAlAs:Zn ~500 Å; GaAs:Zn ~1-2 μm; GaAs:Se ~4-6 μm.

The growth of these structures will be described and a detailed discussion of the device performance characteristics will be given.

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IIIb-5 Properties of Alternate-Monolayer $(GaAs)_n(AlAs)_m$ Crystals—

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By utilizing the smoothness and control of molecular beam epitaxial growth of GaAs and AlAs, layered structures have been grown consisting of repeated alternate depositions of *n* monolayers of GaAs and *m* monolayers of AlAs in which *n* and *m* are as small as unity. The periodicity and perfection of a series of such samples have been measured with transmission electron microscopy and X-ray diffraction. A number of their properties have been investigated and compared with those of thicker layers and of random $Al_xGa_{1-x}As$ layers of the same average composition. Electron tunneling between layers occurs more freely than in thicker layers, giving rise to energy band edges and band gaps intermediate between those of GaAs and AlAs. This permits waveguiding of light and confinement of electrons by alternate monolayer material. Because of the greater order of the monolayer crystals, they have narrower energy bands and wider band gaps than comparable random $Al_xGa_{1-x}As$. Their layered structure produces birefringence and polarized photoluminescence, and introduces new zone boundaries in the dispersion of both electrons and phonons, leading to new modes of observable excitations.

IIIb-5.5 Liquid Phase Epitaxial InGaPAs Multilayered Heterojunction Lasers Exhibiting "Quantum Size Effects"* (Late paper)—

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Utilizing molecular beam epitaxy (MBE) for the growth of successive thin crystal layers, other workers have reported various multilayered AlGaAs-GaAs structures in which the individual layers are thin enough to lead to quantum size effects (QSE). In the present work we show that *multilayer* structures consisting of alternate thin layers of InP and lattice-matched InGaPAs can be grown (~640°C) via liquid phase epitaxy (LPE) with layer thicknesses <500 Å. Double heterojunction (DH) laser diodes are demonstrated in which the InGaPAs-InP thin multilayers are employed as the "active region" between more widely spaced (0.6-1 μm) n-type and p-type InP confining layers. For multilayer DH structures with 400-500 Å thick quaternary layers (11 quaternary layers, $\Delta E_g < 200$ meV) the recombination radiation extends noticeably to *higher energy* (because of carrier confinement, QSE) with the emission intensity decreasing (at higher energy) as a smooth ramp rather than a Boltzmann tail. For thinner quaternary layers (~200 Å, 6 quaternary layers), and thus more widely spaced confined-particle states, the higher energy side of the recombination radiation spectrum decays as much as for a standard double heterojunction but with more noticeable structure (peaks and bumps in the intensity). In spite of the InP spacer layers between the thin quaternary layers and the fact that carriers are injected via these layers, *no* InP recombination radiation is observed.

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IIIb-6 Ion Implantation in InP*—

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