Integrated Enhanced Epitaxy of Opto-electronic Materials

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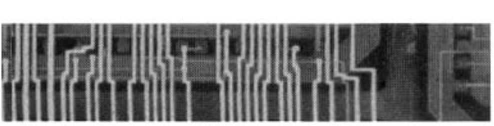
Integrated optical and electronic devices require the fabrication of many different components, each with its own material and structural requirements, on one chip. To achieve optimum performance of an integrated device, each individual device structure should fulfill its optimum material, thickness, and doping requirements. Current activities in device integration have relied mainly on the same multilayer structure to fabricate the different optical and electronic components. Thus, a single or multilayer structure that is optimum for one particular device—for example, a field-effect transistor (FET)—might not satisfy the device structure required for a detector or laser.

Previous efforts to reduce such limitations include making compromises between different device structures, selectively etching unwanted layers, or ion implanting to selectively dope different device structures. The necessary processing usually requires several separate growth steps as well as masking, etching, and lift-off, which may result in low yield. Selective growth by both MBE and metalorganic chemical vapor deposition (MOCVD) through windows in a SiO_2 mask layer has also been reported; however, the same layered structure is deposited in each area.



Laser assisted chemical vapor deposition (LCVD) can provide another approach to address current material problems facing the integration of opto-electronic devices. By using the LCVD approach, devices with different structural and doping requirements can be deposited selectively and independently on the same substrate, with their locations accurately determined using a laser beam scanner (<1 μm resolution). Since the substrate temperature used in this technique is fairly low (<400°C), growth only occurs on the area exposed to the laser beam. This low temperature deposition offers advantages such as an abrupt doping profile, reduced interdiffusion between the heterointerfaces, and reduced outdiffusion of impurities from the substrate.

The LCVD system consists of a vertical MOCVD reactor operated at atmospheric pressure, an Ar ion laser operated at multiple wavelength (488-514 nm), and a computer controlled X-Y laser beam scanner. Achieving selective area epitaxy using LCVD requires keeping the substrate temperature in the range of 300-400°C. Higher substrate temperatures in the presence of organometallic sources induces nonselective deposition on areas of the substrate not exposed to laser light; hence, the LCVD technique loses its selective nature at higher substrate temperatures. On the other hand, a substrate temperature lower than this range requires a higher laser power density, which may produce excessive local heating and accompanying local thermal stresses. Figure 1 demonstrates the direct writing of GaAs films by the LCVD technique and the effect of the growth conditions such as laser power density on the quality of the deposited films.

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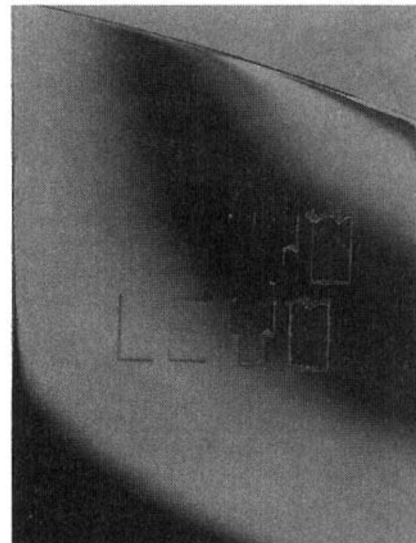
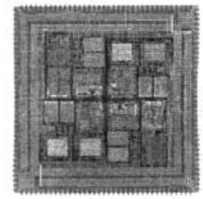


FIGURE 1. DIRECT WRITING OF GAAS FILMS BY LCVD (LASER CHEMICAL VAPOR DEPOSITION) ON GAAS SUBSTRATE. THE QUALITY OF THE DEPOSITED FILMS DEPENDS ON GROWTH CONDITIONS. "L" AND "C" ARE SINGLE CRYSTALS; "V" AND "D" ARE POLYCRYSTALLINE.

The LCVD technique was used in the selective depositions of two device structures: Metal Semiconductor Field Effect Transistors (MESFET) and p-i-n photodetectors, as shown in Figures 2a and 2b, respectively.

The MESFET structure (Fig. 2a), grown on a semi-insulating GaAs substrate, consists of a 0.5 μm undoped GaAs buffer layer and a 0.16 μm silicon-doped channel layer with a doping concentration of 3.4×10^{17} cm^{-3}. The undoped GaAs was found to be highly resistive. The MESFET was then fabricated by standard processing. It has a gate size $L \times W = 1.5$ μm × 75 μm and source-drain separation of 5 μm. The metals used for the Schottky contact and ohmic contacts were Ti/Au and AuGe/Ni/Au, respectively. The Schottky gate contact has an ideality



factor of 1.15, indicating good material quality in the doped channel layer. The reverse breakdown characteristic between the gate and the drain shows a breakdown voltage of about 38V at a leakage current density of 1 $\mu A/(\mu m)^2$. The pinch-off characteristic is good; therefore, no dominant leakage path is present. Also, the output conductance dI_{ds}/dV_{ds} of the device in the saturation region is nearly zero, implying good insulation in the intrinsic buffer layer and good interfaces. The MESFET has a transconductance g_m of about 110 mS/mm, which is comparable to a conventionally built device with similar dimensions.

The p-i-n structure shown in Figure 2b was similarly grown. However, we confronted the problem of lack of selectivity with DEZn and DMZn as the p^+ dopant when the substrate is thermally biased to 400°C. We found that Zn doping using DMZn can be selective if the substrate is maintained below 300°C. The characteristics of the fabricated detectors grown by the LCVD technique are comparable to those grown by MOCVD or MBE techniques. For example, the detector has an external quantum efficiency of about 60% (no AR coating), and the impulse response of the diode has a FWHM of 150 ps, corresponding to a cutoff frequency of 2 GHz.

The LCVD technique has demonstrated the capability of selective deposition of device quality multilayer structures. Optoelectronic devices fabricated using LCVD have performances comparable to their MBE or MOCVD counterparts. Thus, with further material development, especially ternary alloys, the LCVD technique can offer a new approach to the integration of optoelectronic devices.

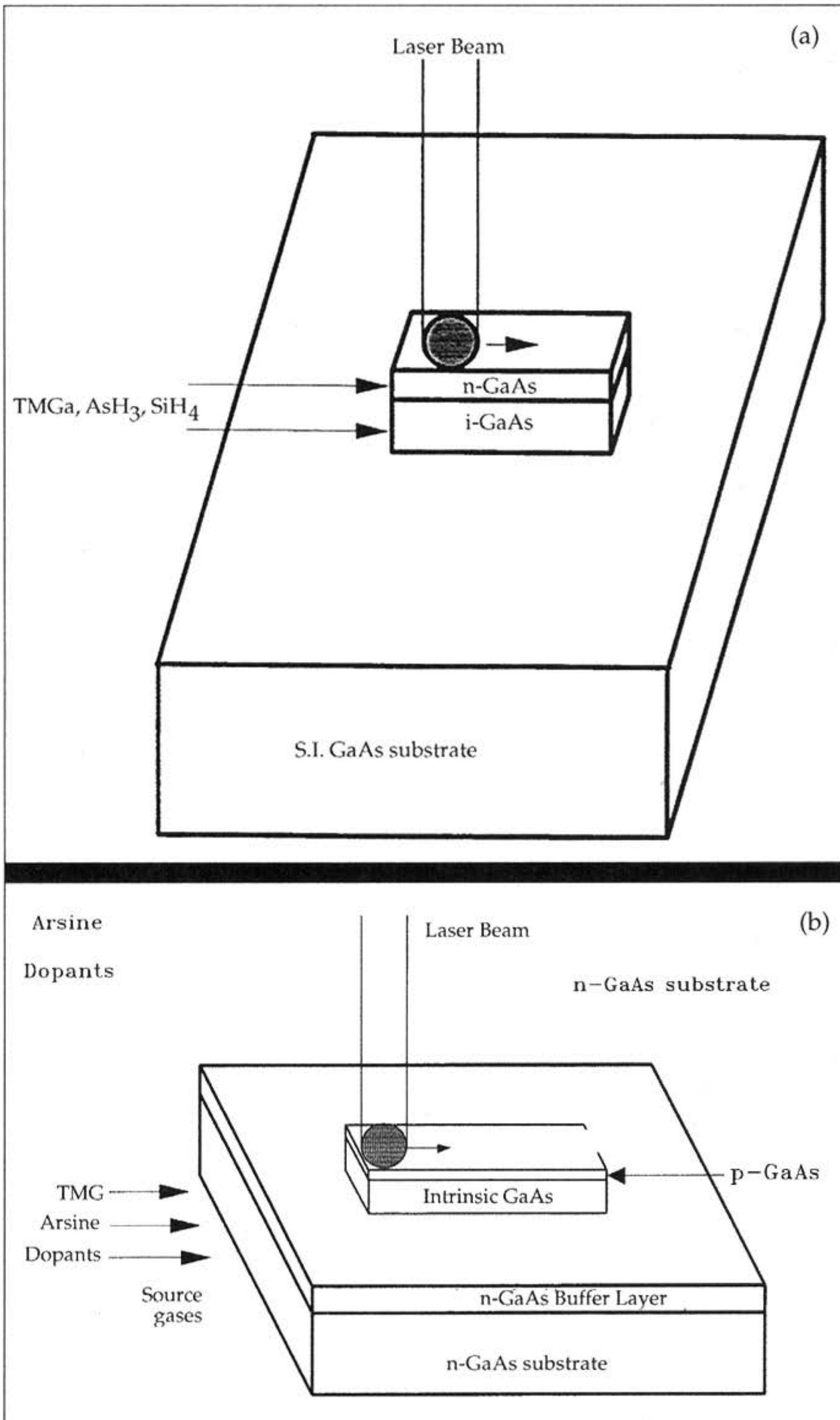


FIGURE 2. a) FIELD EFFECT TRANSISTOR STRUCTURE b) P-I-N PHOTODETECTOR STRUCTURE.