REGROWTH OF GaAs QUANTUM WELLS ON GaAs LIFTOFF FILMS 'VAN DER WAALS BONDED' TO SILICON SUBSTRATES

Indexing terms: Semiconductor devices and materials, Epitaxy, GaAs, Silicon

We report the first epitaxial regrowth on lifted-off large-area micron-thick single-crystal GaAs films bonded by surface tension (van der Waals) forces to a foreign substrate. GaAs quantum wells grown by MOCVD on a GaAs film which had been van der Waals bonded to an Si substrate showed linewidths and luminescence efficiencies comparable to those grown directly on GaAs substrates.

In the field of electronic materials there has been a persistent interest in the integration of high-quality epitaxial thin-film semiconductor layers with arbitrary crystalline or glass substrates. For example, thin electronic-quality single-crystal GaAs layers on crystalline silicon substrates would allow the two technologies to be combined. The economic possibilities have led to a massive effort[1] on lattice-mismatched heteroepitaxial growth. Recently, however, a new and more flexible approach[2] has been attracting increasing[3] attention.

In this new approach, perfect epitaxial quality AlGaAs thin films are lifted off lattice-matched GaAs growth substrates by means of an ultrathin AlAs release layer. Advantage is taken of the extremely selective etching ($\geq 10^7$) of AlAs in dilute hydrofluoric acid, permitting large area (cm^2) epitaxial AlGaAs films to become undercut. The GaAs substrate is left intact and can be reused if so desired, while the epitaxial thin film can be cemented or 'van der Waals bonded' by surface tension to any arbitrary substrate.

At this point two divergent paths suggest themselves:

(1) GaAs wafers can be fully processed and then the devices can be lifted off and bonded to any substrate.

(2) An epitaxial film of GaAs can be 'van der Waals bonded' to a high-temperature substrate and then used for regrowth of further epitaxial layers.

The first of these options is technically straightforward. As an example, we have already demonstrated[4] GaAs double heterostructure lasers on glass. The second option, regrowth, incorporates the foreign substrate at an earlier stage of the device fabrication sequence, but it requires that the GaAs film/substrate combination be reheated back to epigrowth temperatures. Thermal expansion mismatch of the foreign substrate can interfere with the quality of epifilm growth. Furthermore, trapped dust particles can become vapourised during heating, producing blisters under the film. This would be unacceptable in a commercial process where yield is paramount. This letter concentrates on the second and more difficult option, regrowth. We have not overcome the thermal expansion and dust particle problems completely, but we have promising initial results.

Molecular beam epitaxy grown GaAs films of 5000 Å thickness were lifted off their original substrates and mounted by 'van der Waals bonding' to silicon and sapphire substrates employing the techniques of Reference 2. Some dust particles tended to become trapped between the film and the substrate, producing small incipient blisters. By heating to growth temperatures very slowly over several hours under vacuum, the gases trapped when the dust particles vapourised tended to dissipate and diffuse away, leaving a relatively small number (1–1000 cm^{-2}) of macroscopic blisters covering $< 1\%$ of the sample area.

The structure was grown in an atmospheric-pressure, horizontal, RF-heated MOCVD reactor using trimethylgallium (TMG), trimethylaluminium (TMA) and arsine. The mole fractions of TMG and TMA were adjusted to achieve growth rates of 5–10 Å/s. Growth was performed at 700°C after a slow heating of the sample to 750°C for oxide removal. No other surface preparation steps were done prior to loading the sample. The structure consisted 30/40/50/70/90 Å GaAs wells separated by 650 Å $Al_{0\cdot48}Ga_{0\cdot52}As$ barrier layers. Since the liftoff film was already of epitaxial quality, the usual surface etching processes to remove polishing damage prior to MOCVD growth were not implemented.

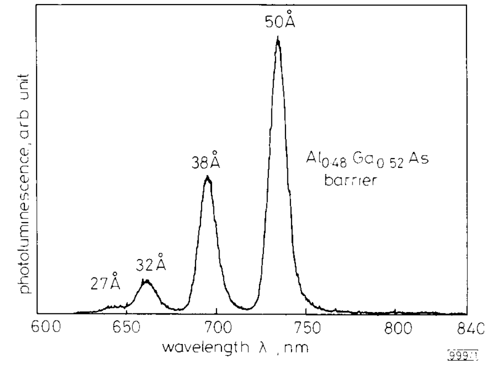

Fig. 1 *5 K luminescence spectrum of series of GaAs quantum wells regrown on 5000 Å GaAs epitaxial liftoff film 'van der Waals bonded' to silicon substrate*

Sharpness of peaks indicates excellent structural quality and thickness uniformity of quantum wells; sample EC 88160

The 5 K photoluminescence spectrum of the quantum wells regrown on a GaAs liftoff film bonded to a silicon wafer is shown in Fig. 1. The thickness indicated above each spectral peak was determined from a finite barrier quantum well model. Unrelaxed strain due to the thermal expansion mismatch between GaAs and Si, if any, would have produced a minor contribution to the spectral shift and was neglected here.

The narrow width of the spectral peaks is a measure of the structural quality and thickness fluctuations of the quantum wells. The low-temperature (excitonic) luminescence efficiency was comparable to that of GaAs quantum wells grown directly on GaAs substrates, although the linewidth was somewhat broader. This corresponded to $\sim \pm 1$ monolayer fluctuation, where a monolayer is 2·8 Å. Scans of the pump beam over the 0·5 cm^2 sample area demonstrated excellent uniformity, provided that the blistered spots were avoided. There was some slight surface roughness under optical microscopy. This could have resulted from the several days' oxidation that occurred as the films awaited their turn to enter the MOCVD chamber.

Blistering, which occurs in the temperature range 250–450°C as the dust particles vapourise, was the biggest problem. This was minimised by slow heating under vacuum. In a clean room environment this problem can be minimised, but possibly never eliminated completely. Nevertheless, we can expect increasing device application via option (1), epitaxial liftoff of completed devices that do not require regrowth.

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Errata

POULTON, G. T., ZHOU, H., and CLARRICOATS, P. J. B.: 'Approximate theory for radiation from mesh reflectors', *Electron. Lett.*, 1988, **24**, (23), pp. 1467–1468

The first unnumbered equation following eqn. 2 should read as follows:

$$F_0 = F/k(1 - R_0)$$

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The simplified eqn. 5 gives an error for the resonance frequency. It is advisable to use the exact form, given by

$$G_u^I = \frac{g_m^2 R_{ds}(1 + (\omega T_j)^2)}{8C_{gs}^2 R_i \omega^2 \sin^2\left(\frac{\omega\tau}{2}\right)} \tag{5}$$

where $j = 1, 2$. The first resonance frequency is then given by

$$f_r = \frac{1}{\tau}$$