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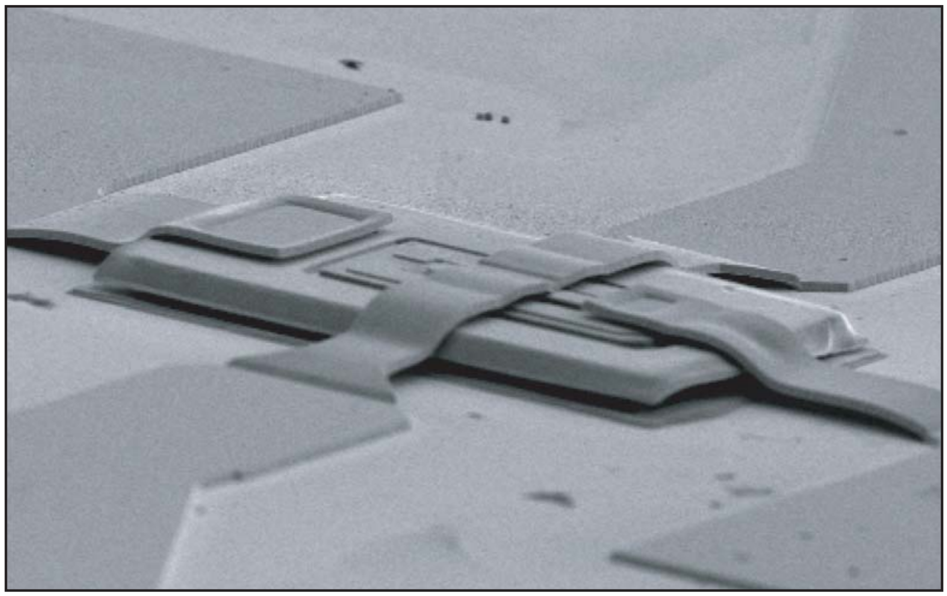
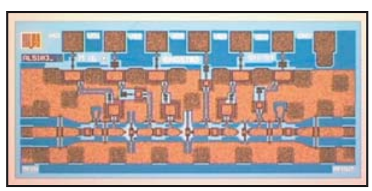
'$In_{0.69}Al_{0.31}As_{0.41}Sb_{0.59}In_{0.27}Ga_{0.73}Sb$ double-heterojunction bipolar transistors with $InAs_{0.66}Sb_{0.34}$ contact layers', J. G. Champlain, R. Magno, R. Bass, D. Park and J. B. Boos

Advanced III-V transistor technology using 6.2 Å materials reaches a record 59 GHz

6.2 Å materials step up

The highest cutoff frequency of double heterojunction bipolar transistors (HBTs) fabricated using 6.2 Å materials has been demonstrated by researchers at the Naval Research Laboratory (NRL) in the US. The team fabricated InAlAsSb/InGaSb HBTs with high conductivity InAsSb layers, and achieved record operation up to 59 GHz, along with improved DC characteristics. The development of these devices is of particular interest for high-speed signal conversion or power limited millimetre-wave applications such as in space or telecommunications.





ABOVE: A scanning electron microscopy image of an InAlAsSb/InGaSb HBT fabricated in the 6.2 Å material system
RIGHT: Sb-based materials are particularly suitable for low-power applications such as in this W-band monolithic microwave integrated circuit using AlSb/InAs produced by Northrop Grumman Space Technology in collaboration with NRL in 2005

Constant benefits

6.2 Å materials, such as InGaSb and InAsSb (where 6.2 Å refers to the lattice constant), have great potential for low-voltage or low-power operation. Their narrow bandgaps lead to high-current densities at much lower biases compared to devices fabricated from 'conventional' III-V materials (such as GaAs-based and InP-related materials). They also offer some of the highest electron and hole mobilities in III-V semiconductors, and devices fabricated in these materials have shown very high-frequency operation and record performance in the area of low-power operation. In general, the 6.2 Å materials are desirable for any application requiring a long battery lifetime, low-power dissipation and/or high-frequency performance.

Although promising in their performance, progress using 6.2 Å materials is slow as the growth of devices is challenging. For example, currently there is no 'native' semi-insulating substrate at these lattice constants, so achieving low defect material growth is difficult. In addition, the difference in the materials, which are either mixed group-V ternaries or mixed group-III and group-V quaternaries at these lattice constants, leads to a very narrow growth window in terms of temperatures, flux beam ratios etc. This mixture of materials also creates significant challenges with the device processing, as processes such as etches that normally work well for conventional arsenide, phosphide or antimonide compounds become ineffective.

A new layer

The device demonstrated by the NRL group in their Letter in this issue is the first $In_{0.69}Al_{0.31}As_{0.41}Sb_{0.59}/In_{0.27}Ga_{0.73}Sb$ double HBT to be successfully fabricated with $InAs_{0.66}Sb_{0.34}$ included as n-type contact layers in the emitter and collector. $InAs_{0.66}Sb_{0.34}$ has a very high electron mobility which greatly reduces the overall resistance. With this material, the device demonstrated lower voltage operation and the highest measured short-circuit current gain cutoff frequency over devices that rely solely on InGaSb as the emitter and collector contact layers. InGaSb still remains the material of choice for p-type base layers, however, and the most appropriate material must be selected according to the application within the device. The biggest challenge that the NRL researchers faced with the realisation of their proposed device was with the etching of the material. A selective etch process very recently developed by a group in France for these materials looks promising to achieve HBTs with shorter base layers for extremely high-frequency performance, and the NRL team will be investigating its use in the future.

Future development

The NRL team now plans to further refine their device, specifically by looking at material choice, layer design and layout to improve the low-voltage and high-frequency operation, and improving the processing elements. In general they are interested in 'pushing' the lattice constant towards 6.3 Å as they expect the improvements and benefits that were seen by going to 6.2 Å to be further enhanced.

"Right now appears to be a critical time for this area of material and device research," commented Dr James Champlain, one of the researchers at NRL. "There has been increased interest in high-speed, low-power electronics associated with areas from THz imaging to high-speed digital circuits and logic. With conventional semiconductor compounds reaching or pushing their limits, new materials must be explored. Researchers have recently begun to look at materials like graphene and carbon nanotubes, which promise very high-speed performance, but are still in their infancy from a device and application perspective and face some practical hurdles to their application beyond research. On the other hand, the 6.2 Å materials, with recent device results, have shown promise and offer attainable solutions in the area of high-speed, low-power electronics."