35-GHz HEMT Amplifiers Fabricated Using Integrated HEMT-HBT Material Grown by Selective MBE

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***Abstract*—We have fabricated 35-GHz balanced low-noise amplifiers using pseudomorphic InGaAs-GaAs HEMT material monolithically integrated with HBT material grown by selective MBE. The 0.2-μm T-gate HEMT amplifiers fabricated using a merged HEMT-HBT process have equivalent gain and noise figure compared to amplifiers fabricated using normal MBE and our baseline HEMT-only process. This demonstration of high performance HEMT amplifiers using integrated HEMT-HBT material and a merged HEMT-HBT process enables the fabrication of a new class of multifunction monolithic microwave integrated circuits.**

MONOLITHIC integration of high electron mobility transistors (HEMT's) with other types of devices, such as heterojunction bipolar transistors (HBT's) or PIN diodes, is very attractive for a variety of microwave and optoelectronic applications. The availability HEMT devices and circuits on the same chip as HBT devices and circuits would enable improvements in microwave circuit performance due to the unique advantages of each device type. Low-noise HEMT front-ends could be used together with high-linearity HBT's for improved amplifier performance. Likewise, HEMT receivers could be integrated with HBT transmitters and HBT base-collector PIN diodes to enable unique single-chip transmit-receive modules with greater performance than can be achieved using either device technology alone. In other circuits, PIN-diode detectors or limiters could be integrated with HEMT amplifiers for optoelectronic applications or for HEMT LNA input overload protection. To date, however, the integration of high performance HEMT devices or circuits has not been demonstrated when monolithically integrated with other device technologies.

Most attempts at multifunction integration of MESFET's or HEMT's with PIN diodes or HBT's have relied on either stacked epitaxial structures using relatively large gate lengths [1], [2] or on merged device profiles where the collector [3] or emitter [4] layer of the HBT structure also serves as the FET layer. Epitaxial overgrowth with 9-μm gate-length FET's [5] and selective regrowth with 0.25-μm gate-length devices [6] has also been reported.

Manuscript received June 9, 1994.
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IEEE Log Number 9405760.

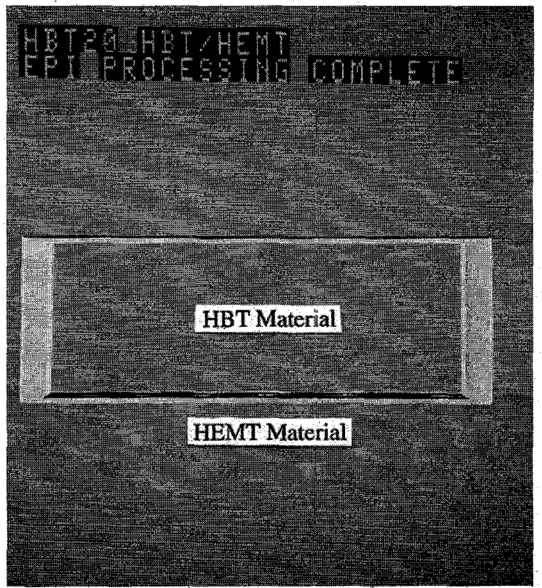


Fig. 1. SEM micrograph of monolithic integration of HEMT and HBT material grown by selective MBE.

We report here the use of a merged HEMT-HBT process to fabricate 35-GHz balanced low-noise amplifiers in pseudomorphic InGaAs-GaAs-AlGaAs HEMT material integrated with GaAs-AlGaAs HBT material grown by selective MBE. The motivation for this work is to demonstrate the feasibility of fabricating high-performance HEMT devices and circuits using a process developed for the simultaneous production of HEMT's and other device technologies such as HBT's and PIN-diodes on the same chip.

The integrated HEMT-HBT epitaxial material was grown by selective molecular beam epitaxy using a process similiar to that reported for the production of complementary npn-pnp HBT integrated circuits [7]. The npn GaAs-AlGaAs HBT structure was grown first, using the same baseline HBT profile as that reported in [7]. This profile is optimized for reliability and for high-linearity applications through 20 GHz. The wafer was patterned with silicon nitride and etched to form HBT islands. The pseudomorphic InGaAs-GaAs HEMT structure was grown on the patterned HBT material, forming high quality epitaxial material in the areas where the HBT material was removed. The HEMT profile used here is our baseline low-noise planar-doped $In_{0.22}Ga_{0.78}As$-$Al_{0.22}Ga_{0.78}As$ structure.

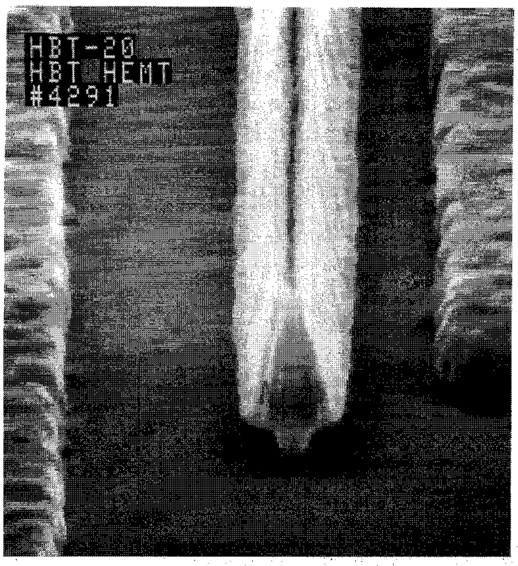


Fig. 2. SEM micrograph of 0.2-μm T-gate fabricated in HEMT material grown by selective MBE.

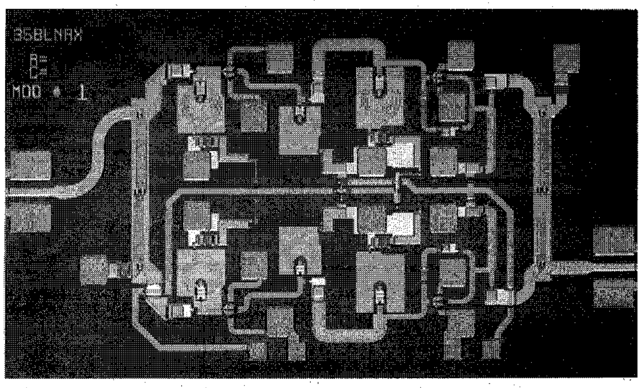


Fig. 3. Fabricated 35-GHz pseudomorphic HEMT balanced low-noise amplifier.

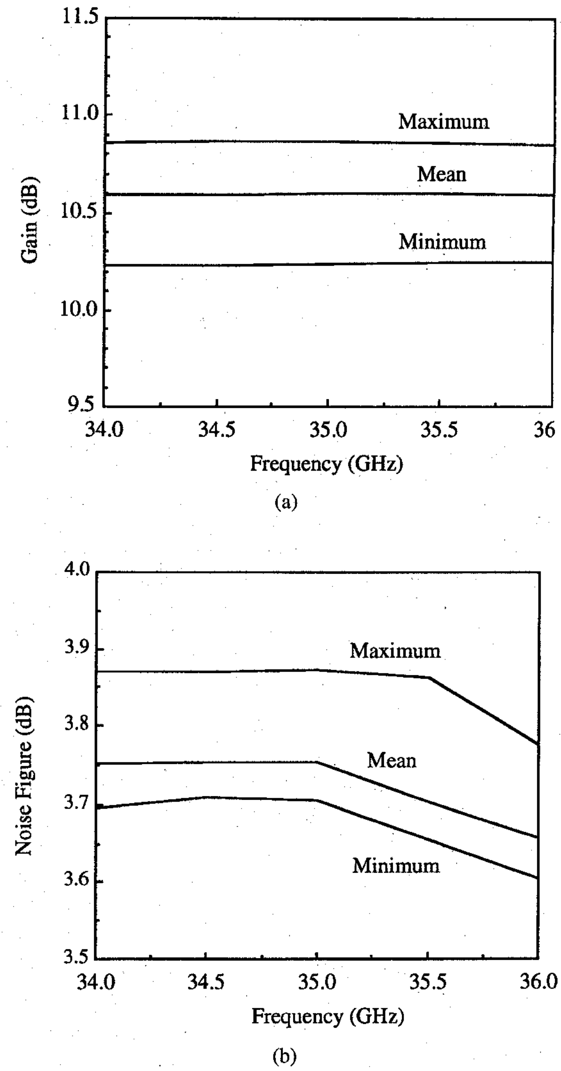


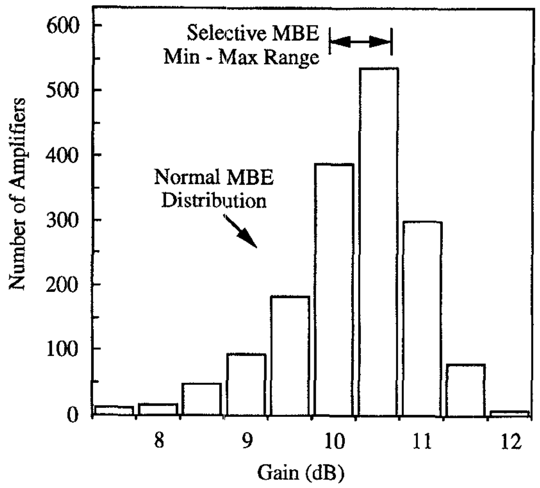
Fig. 4. (a) Gain and (b) noise performance of 35-GHz balanced low-noise amplifier fabricated by merged HEMT-HBT process in pseudomorphic InGaAs-GaAs HEMT material grown by selective MBE.

The polycrystalline HEMT material and the silicon nitride deposited on the protected HBT islands was removed by wet etching, resulting in starting material for the HEMT process as shown in Fig. 1.

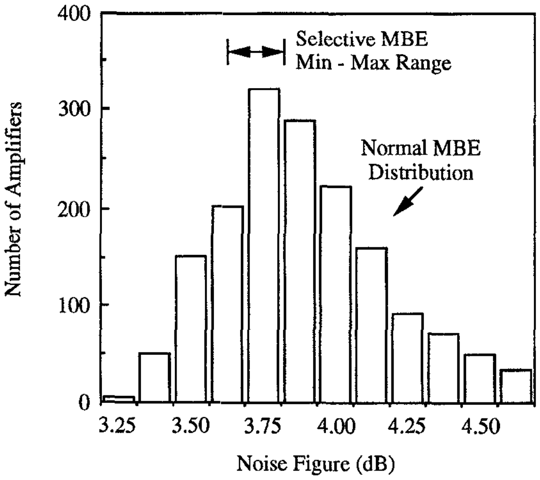
The 35-GHz low-noise HEMT amplifiers were fabricated using a merged HEMT-HBT process that allows the simultaneous production of HEMT devices and circuits in the HEMT epitaxial material and HBT devices and circuits in the HBT epitaxial material. The HEMT Ni/AuGe/Ag/Au ohmic metal was evaporated and rapid thermal annealed. The HBT emitter mesa was etched and the base mesa metal deposited. The HBT base and Schottky mesas were etched, and the emitter and collector ohmics were deposited and annealed. The HBT and HEMT devices were isolated at the same time using oxygen ion implantation. The HEMT T-gate was then written by electron beam lithography. Thin-film resistors, capacitors, inductors, airbridge interconnects, wafer thinning, and backside vias complete the HEMT and HBT circuit fabrication process. The 0.2-μm T-gate shown in Fig. 2 has excellent channel morphology with a narrow recess as desired for low noise applications, indicating that the merged HEMT-HBT process has not affected the normal gate process.

The 35-GHz balanced, low-noise HEMT amplifier used for this demonstration is designed for 9-dB flat gain response from 34 to 36 GHz, with less than 5-dB noise Figure. The fabricated circuit is shown in Fig. 3. Circuit results for nine amplifiers fabricated in HEMT material grown by selective MBE and fabricated using the merged HEMT-HBT process are shown in Fig. 4. Circuit gain is essentially flat across the 2-GHz band, with a minimum measured gain of greater than 10 dB. Amplifier noise figure ranges from a minimum of 3.6 dB at 36 GHz to a maximum of $\sim$3.9 dB at 34 GHz. The gain and noise figure for these circuits meet all specifications for this amplifier, despite the extra MBE growth and circuit fabrication steps associated with the integrated HEMT-HBT process.

The amplifier results obtained at 35 GHz using integrated HEMT-HBT material and our merged HEMT-HBT fabrication process are compared in Fig. 5 with amplifier results obtained at 35 GHz using normal MBE material and our baseline HEMT-only process. The range in gain and noise figure from minimum to maximum as measured on nine amplifiers



(a)



(b)

Fig. 5. (a) Gain and (b) noise performance comparison of 35-GHz balanced low-noise amplifiers fabricated by merged HEMT-HBT process (9 amplifiers) and by normal HEMT-only production process (~1600 amplifiers).

fabricated by the HEMT-HBT process is compared to the gain and noise figure results of over 1600 amplifiers fabricated using our baseline HEMT-only production process. The gain and noise figure obtained using the merged HEMT-HBT process is representative of typical amplifier results obtained using the HEMT-only production process.

The performance of these 35-GHz balanced low-noise amplifiers fabricated by selective MBE and using a merged HEMT-HBT process is in all respects equivalent to that obtained using our baseline HEMT process and demonstrates the suitability of this merged HEMT-HBT process for the production of high-performance HEMT circuits in an integrated HEMT-HBT environment. This in turn enables the monolithic integration of high performance HEMT's with other device technologies, creating a new class of multifunction monolithic microwave integrated circuits with functions and performance not currently available with a single technology.

Acknowledgment

The authors gratefully acknoweldge the assistance of Tim Naeole, Po-Hsin Liu, Annika Freudenthal, Thomas R. Block, and An-Chich Han in the production of these results.

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