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Yield Improvement in Fabrication of Edge Emitting Transistor Lasers by optimized BCB planarization

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INTRODUCTION

The base current of the transistor supports recombination and can be used, by inserting a quantum well in the base region to trade off electrical gain for optical generation, to transform the transistor (provided a high Q cavity for stimulated emission) into a laser. Thus the device acts as both an HBT (forward biased) and a semiconductor laser [1]. The quantum well recombination competes with transport through the base region to limit the average lifetime of the minority carriers (electrons) in the base to the order of ~ 30ps [2]. The quantum well transistor laser is a novel three-port opto-electronic device that is capable of high-speed, resonance-free optical RF response [3]. In this work we discuss the failure mode of the previous generation process, the identification of the critical issue causing yield loss and the solution along with yield and device results.

DEVICE FABRICATION

The epitaxial structure of the TL starts with a heavily doped n-type 5000Å GaAs buffer grown on SI-GaAs. Next a 5000Å n-type $Al_{0.95}Ga_{0.05}As$ layer that functions as both the sub-collector and as the laser lower cladding. The collector contact is a 200Å heavily-doped n-type GaAs layer. A 120Å $In_{0.49}Ga_{0.51}P$ etch stop layer is included for facilitating fabrication followed by a 600Å lightly-doped GaAs collector. A 1000Å heavily-doped p-type AlGaAs/InGaAs/GaAs layer serves as the base and includes one 120Å undoped InGaAs quantum well designed for 980nm emission. The emitter is a lightly-doped n-type 250Å $In_{0.49}Ga_{0.51}P$ layer followed by 4000Å of n-type oxidizable $Al_{0.95\text{-}0.99}Ga_{0.05\text{-}0.01}As$ upper cladding which serves (via lateral oxidation [4]) to confine the current injection and laser aperture. The emitter contact layer consists of 1000Å heavily-doped n-type GaAs. Device fabrication of the HBTL consists of 9 photolithographic steps. Wet etching is used for all mesas and isolation. BCB planarization is used to facilitate post interconnection followed by a final polyimide via interconnection to realize the common emitter HBTL structure. The wafer is lapped to a thickness of 25μm, polished and cleaved into bars.

FAILURE AND BCB SPIN NON UNIFORMITY

The "open B-E diode" failure mode is a characteristic of the low yield of the previous generation process. PCM analysis shows Base and Emitter ohmic contact and post and via resistances to be within specifications. The emitter contact for this process is deposited last, after BCB planarization and etchback to expose the emitter mesa. The failure is repeatable for the process and even the etchback PCMs on the layout are incapable of identifying the cause. FIB cross sectioning reveals a discontinuity in the Emitter Metal overlap which is responsible for the failure. BCB over-etch coupled with the re-entrant etch profile of the emitter cap causes this (shown in Figure 1) and results in the B-E open failure mode. BCB-46 is the polymer used in this process. FIB and SEM analysis reveal excessive non-uniformity in BCB spin-profile due to high topography, uneven feature density over device and PCM areas (Figure 3) and thin BCB. This results in catastrophic device failure of many lasers in order to yield a few. The PCM design is poor and does not reflect the actual device.

SOLUTION AND RESULTS

BCB-57 coupled with a faster cure is used in the next generation of the process. The spin height is thicker and planarization much better. The PCM and device regions still have different BCB spin heights; however, the variation between devices is greatly reduced allowing a much tighter etch-back mesa height control. Figure 2 Shows the FIB cross section of a functioning device with excellent connection between the emitter metal and mesa. Device yield is improved from ~ 10% to ~ 85% which allows for a stable baseline process to provide a test bed for future experiments. Figure 4 shows 15.34GHz 3dB optical modulation bandwidth for a 400μm TL at 0°C fabricated using this process. The post PCM design is revealed to be flawed and the structures do not yield any worthwhile information. Improvements are suggested to be incorporated into the next generation of the mask set.

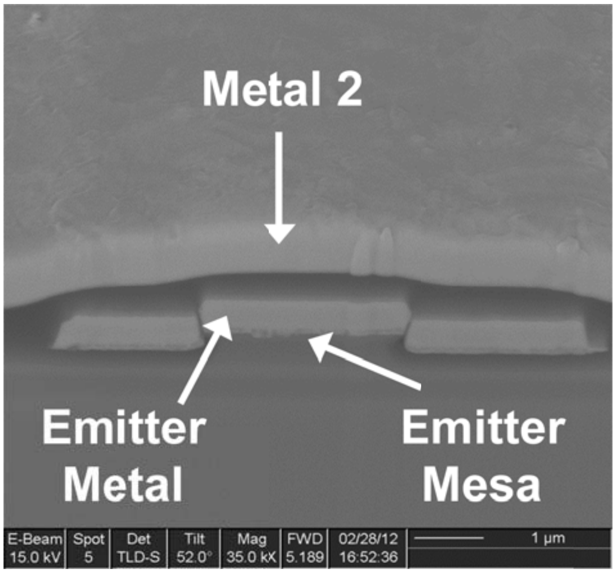

Figure 1: FIB cross-section of failed device showing discontinuity in Emitter Metal overlap due to BCB over etch.

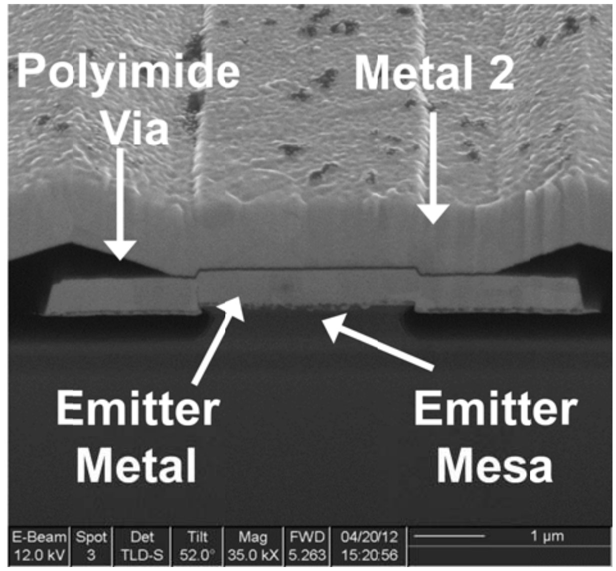

Figure 2: FIB cross-section of working device showing excellent continuity of emitter metal, sloping poly-imide vias and Metal - 2 connecting to emitter metal.

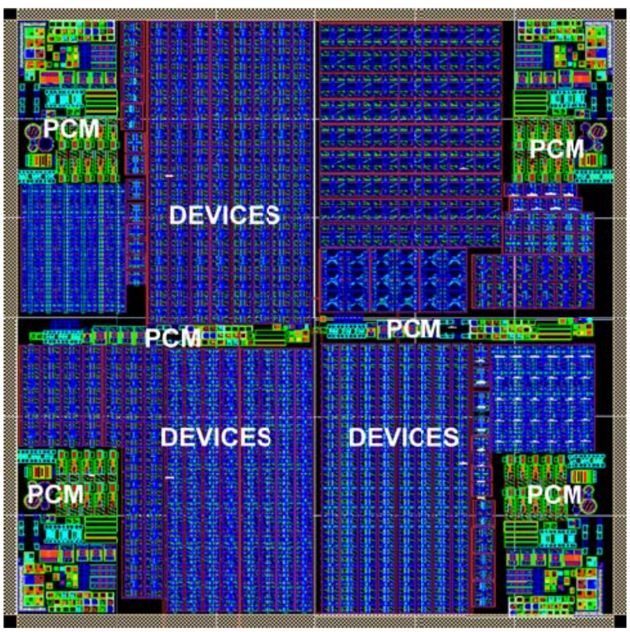

Figure 3: TL4 mask layout showing all processed layers to illustrate feature density variation across different length laser devices and PCM regions on the wafer.

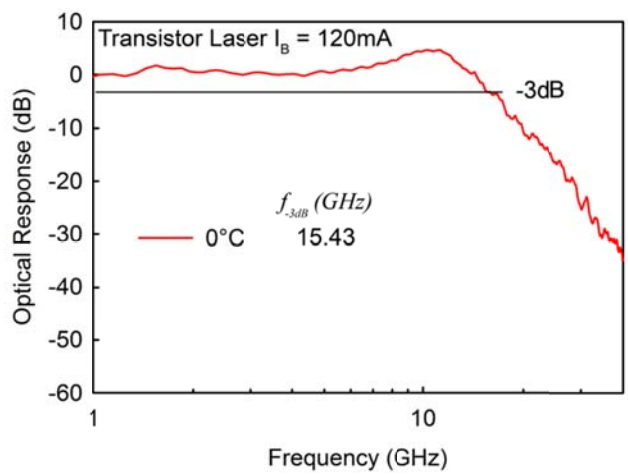

Figure 4: Frequency response of the transistor laser fabricated with the improced process showing a measured S_{31} optical response (smoothed).

References

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