Relaxation of active acoustic emission sources during the natural aging of A^3B^5 epitaxial structures

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The aging processes of A^3B^5 epitaxial light-emitting structures have been shown to reduce acoustic emission (AE) intensity, AE count, and to raise the AE onset threshold while an increased change rate of the direct current through junction results in that AE onset threshold becomes shifted towards lower currents, the failure currents drop, and AE intensity and AE count increase.

Показано, что процессы старения эпитаксиальных светоизлучающих структур на основе соединений A^3B^5 уменьшают интенсивность акустической эмиссии (АЭ), суммарную АЭ и повышают порог возникновения АЭ, а увеличение скорости изменения постоянного электрического тока через переход — к смещению порога возникновения АЭ в область меньших токов, уменьшению токов разрушения, а также возрастанию интенсивности АЭ и суммарной эмиссии.

The short-time appearance and breakdown of mechanical stresses in local domains due to an external loading results in a spontaneous chaotic acoustic emission (AE) of the materials [1], including microdomains of semiconductor crystals [2, 3]. The AE source can be induced in this case by thermo-mechanical stresses caused by direct currents passing the light-emitting diode LED structure due to inhomogeneity of the epitaxial structure resistance [3] The active AE source is in fact a source of internal ultrasonic vibrations as well as a local domain where the material structure is subjected to a dramatic rearrangement [1].

Previous studies [3, 4] of acoustic emission in epitaxial light-emitting structures based on A^3B^5 solid solutions, namely, in $Ga_{0.7}Al_{0.3}As$ and $Ga_{0.65}Al_{0.35}As$ p^+-p-n structures and $Ga_{0.85}As_{0.15}$ n^+-n-p ones as well as in GaP:N *p-n* structure, have shown that in some samples, the direct current density J_i can exceed the producer-declared nominal value J_{nom} by a factor of 10 to 20 during first two or three years after manufacturing date, neither the sample failure nor AE being observed in this case. For other samples, however, the AE was observed even at $J_i < J_{nom}$.

This fact evidences directly differences in initial concentrations and distributions of active AE sources (structure defects) arising in the growth course, in spite of the strain energy decrease caused by the system elastic relaxation. That is, the major part of dislocations in structures of inhomogeneous composition remain to be nonequilibrium defects [5] fixed at weak stoppers, including point defects. In fact, as the growth process is over, the heterostructures can keep a complex metastable non-relaxed state at a high level of internal mechanical stresses inhomogeneous over volume of crystal. The purpose of this work is to study the effect of prolonged natural aging of those structures on the AE dynamics.

The AE signal was recorded using piezoelectric sensors within the 500 to 1000 kHz frequency range. The electric signals of continuous AE were recorded by a specialized AF-15 instrument while the discrete high-energy AE signals were taken from the AF-15 output using a chart recorder. The compound fixing the crystals in industrial LED was used as electric insulator and acoustic buffer. The direct current was passed through samples with 500×500μm^2 crystals at the density J_i = (0.2 to 20)·10^5 A/m^2. The current density was increased in step-by-step mode as in [3, 4], each J_{i+1} = (2...1.5...1.2)·J_i. To ensure the Kaiser law is met, AE was registered till the guaranteed activation of all AE sources potentially active at the respective J_i, that is, till the AE was over. Therefore, the time periods between the current variations Δt_i was 3 to 10 min.

As compared to the studies [3, 4] carried out in time intervals about 2.5·10^8 s (about 8 years), the typical threshold current density J_{th} corresponding to AE onset threshold has been found to increase substantially. During the LED storage time (about 16 to 18 years), the J_{th} value has been changed from (0.2 to 2)·10^5 A/m^2 to (6 to 16)·10^5 A/m^2 and exceeds considerably the J_{nom} for those structures (about 0.4·10^5 A/m^2). The failure current density $J_{fl} > J_{th}$ is about (16 to 20)·10^5 A/m^2 for the structures under study.

The AE dynamics was observed to vary considerably. In fresh-made samples, the discrete AE at every $J_i > J_{th}$ step (independent of the structure type) looks as a chaotic sequence of pulses (Fig. 1a) damping in time and is accompanied by a low-energy continuous AE. In naturally aged structures, burst AE at $J_i > J_{th}$ looked for most samples as seldom single pulses with amplitudes attaining at every J_{fl} (Fig. 1b). The AE count and AE intensity (pulses per second) decreased considerably (by a factor of 3 to 10), the current increase parameters being the same. At accelerated current variations (large steps J_{i+1} = (2.5 to 3)·J_i or short time intervals Δt_i = 0.5 to 2 min) AE count rate and AE count increased sharply while J_{th} decreased considerably almost down to fresh-made sample level. This indicates that the relaxation process character depends on the number of AE sources activated simultaneously.

The large experimental values of J_i at substantial changes in AE dynamics (e.g., its absence at J_{nom}) evidences the absence (or the presence of very small number) of AE sources having relatively low activation energy. Since the existence of an AE source is related explicitly with a material structure distortion in a local domain, this points that during aging, the number of defects capable of change their state under weak external influences is reduced. It is the dislocation motion that is believed to be among AE mechanisms in semiconductor crystals [2, 6]. Thermal annealing (artificial aging) is asserted to influence significantly the AE dynamics in dislocation-containing crystals under thermal and current factors [6]. Since the defect structure of A^3B^5 epitaxial layers is much more complex [5], the set of active and passive AE sources cannot be restricted to non-interacting dislocation only, it is necessary to take in account the formation and displacements of microinclusions of gallium, uncontrolled dopants, as well as of large number of surface and volume defects associated with technological treatments.

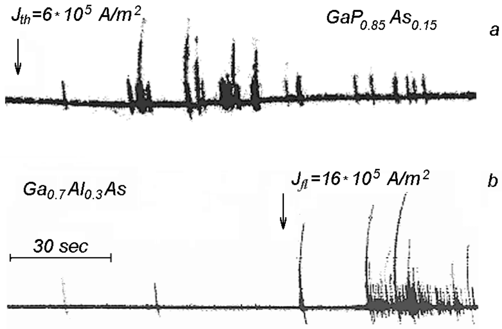

Fig. 1. Burst AE at the onset threshold (a); typical structure failure (b). ↓, the current establishing moment.

It is obvious that under such conditions, the relative increase in J_{fl} may be associated with the aging processes resulting in essential changes of the material internal defect structure in a time of about 5·10^8 s. During the aging, the relative smoothing of local densities of point and linear defects over volume of sample competes with the predominating binding of points defects and dislocations into clusters. In this process, 2D and 3D structure defects are of a considerable importance. Due to the latter, at the total structure defect density being the same, the number of potentially active sources of low-energy continuous AE is decreased considerably under simultaneous formation of complex defects (new sources of high-energy burst AE) requiring a high activation energy [1, 3, 7]. Properly speaking, the appearance of burst AE at super-high current densities may be related to rearrangements in local internal domains having as centers one or several neighboring 3D defects. The low-energy continuous AE is a consequence of dislocation motion [1] where the point defects of studied structures (N atoms, Zn–O complexes, etc.) are also of importance.

Thus, relaxation of AE sources (reduction of active number of those) in epitaxial LED is related to the natural aging processes, that is, to transition into a new metastable state where, due to defect redistribution in local domains and changes of the defect states, AE count rate and AE count decrease, the AE onset threshold increases, the actuation dynamics of AE sources and the AE type are changed. In the same time, increasing J_i variation rate results in a J_{th} shift towards lower currents, a decrease of J_{fl}, increase of AE count and AE count rate, thus pointing to recovery of a metastable state of the defect structure including a large number of active AE sources.

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Релаксація активних джерел акустичної емісії в процесі природного старіння епітаксійних структур A^3B^5

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Показано, що процеси старіння епітаксійних світловипромінювальних структур на основі сполук A^3B^5 зменшують інтенсивність акустичної емісії (АЄ), сумарну АЄ та підвищують поріг виникнення АЄ, а збільшення швидкості зміни постійного електричного струму через перехід — до зміщення порогу виникнення АЄ в область менших струмів, зменшення струмів руйнування, зростання сумарної емісії та інтенсивності АЄ.