III-Nitride Unipolar Light Emitting Devices

Y.G.Shreter[1], Y.T.Rebane[1] and W.N.Wang[2]

[1]A.F.Ioffe Physico-Technical Institute RAS,
26, Polytechnicheskaya str , 194021 St.Petersburg, Russia
[2] Department of Physics, University of Bath, Bath BA2 7AY, UK

Tel: +7-(812)-9606185 FAX : +7 (812) 5527888, e-mail: shreter@pop.convey.ru

A significant progress has been achieved recently in the field of visible light emitting diodes on the base of wide-band-gap gallium, aluminium and indium nitride semiconductors [1]. However, there is a problem to get a good p-type conductivity for these materials which blocks further development of the high power lasers and light emitting diodes for visible spectral range. To overcome these difficulties we suggest to use for light generation the III-Nitride semiconductors of n-type solely.

The main idea of unipolar light emitting device (U-LED) is to create an analogy of n-p junction between two superlattices with à shallow and à deep subbands. The superlattice with shallow subband acts às an effective n-type semiconductor, whereas the superlattice with shallow subband plays role of an effective p-type semiconductor. In the U-LED the radiation arises not due to recombination of the electrons and holes as it takes place in usual light emitting diodes but due to the electron transitions from shallow subband superlattice into the deep sub-band superlattice accompanying by the electron energy relaxation via emission of photons. The device works like usual LED at the forward bias, but has a great advantage that it is possible to tune resonantly the sub-band energy position to any optically active two-level quantum structures like quantum wells, impurities or quantum dots at the interface between the superlattices.

The conduction band off-set between AlN and InN is about 3 eV and this value can be reduced by use the alloy of AlGaInN. This provides electron transitions between two superlattices based on these alloys with energies in the range of 0-3 eV, which covers visible and infrared range of the spectra. The quantum efficiency of these transitions could be enhanced by inserting between two superlattices some optically active layer with two quantum states, which can be: a specially designed quantum well, impurity layer or quantum dot layer. The active layer can be directly electrically pumped through the superlattice subbands.

The efficiency of the device is limited by the non-radiative energy relaxation channel related to the phonon emission time $\tau_{phonon} = 1.3\ 10^{-12}$ s and is rather low ~0.2% for the simple U-LED without active layer or U-LED with single quantum well active layer.

À significant increase in the efficiency can be achieved with use of the active layer doped with deep acceptors. In this case the optical transitions take place from the quantum well subband of the active layer into the deep acceptor impurity band, Fig.1. The transition metals Fe and Ni are considered as a possible deep acceptors for the active layer in GaInN/AlN superlattices. The corresponding acceptor energy levels are ~ 3 eV above the edge of the valence band of the nitride alloy and the optical transition from quantum well subband to the acceptor level can be tuned to any position in the visible spectral range. The photon emission time in this case can be estimated as $\tau_{photon} \sim 10/BN_{à} = 10^{-10}$ s for $N_{à} = 10^{21}$ cm^{-3}, where $B = 10^{-10}$ cm^3/s is van Roosbroek and Shockley radiative constant, $N_{à}$ is the acceptor concentration in the active layer and factor 10 arises from 0.1 admixture of the nitrogen p-orbitals to the transition ion d-orbitals estimated with the empirical tight-binding parameters.

Thus, using the active layers with the optical transitions from quantum well subband to the transition metal impurity band can provide U-LEDs with efficiency up to 20%.

À further suppression of the phonon non-radiative recombination channel and increase of the efficiency can be achieved as à result of lateral confinement when on array of quantum dots or δ-doped layer of two-level impurity centres are used as an active layer.

A serial connection of unipolar light emitting devices allows to increase the output power and obtain any spectra in visible region, including white light via combination of different pairs of the superlattices.

With a resonator adjusted the structure made of the same pairs of the superlattices allows, in principal, to obtain a laser for visible spectra region somewhat similar to the infrared cascade laser suggested by Kasarinov and Suris [1] and realised recently by Capasso and co-workers [2].

References

[1] R.Kazarinov and R.Suris, Sov.Phys.-Semicond., **5**, 707 (1971)
[2] J.Faist, F.Capasso, D.L.Sivco, C.Sirtori, A.L.Hutchinson, and A.Y.Cho, Science **264**, 553 (1994)

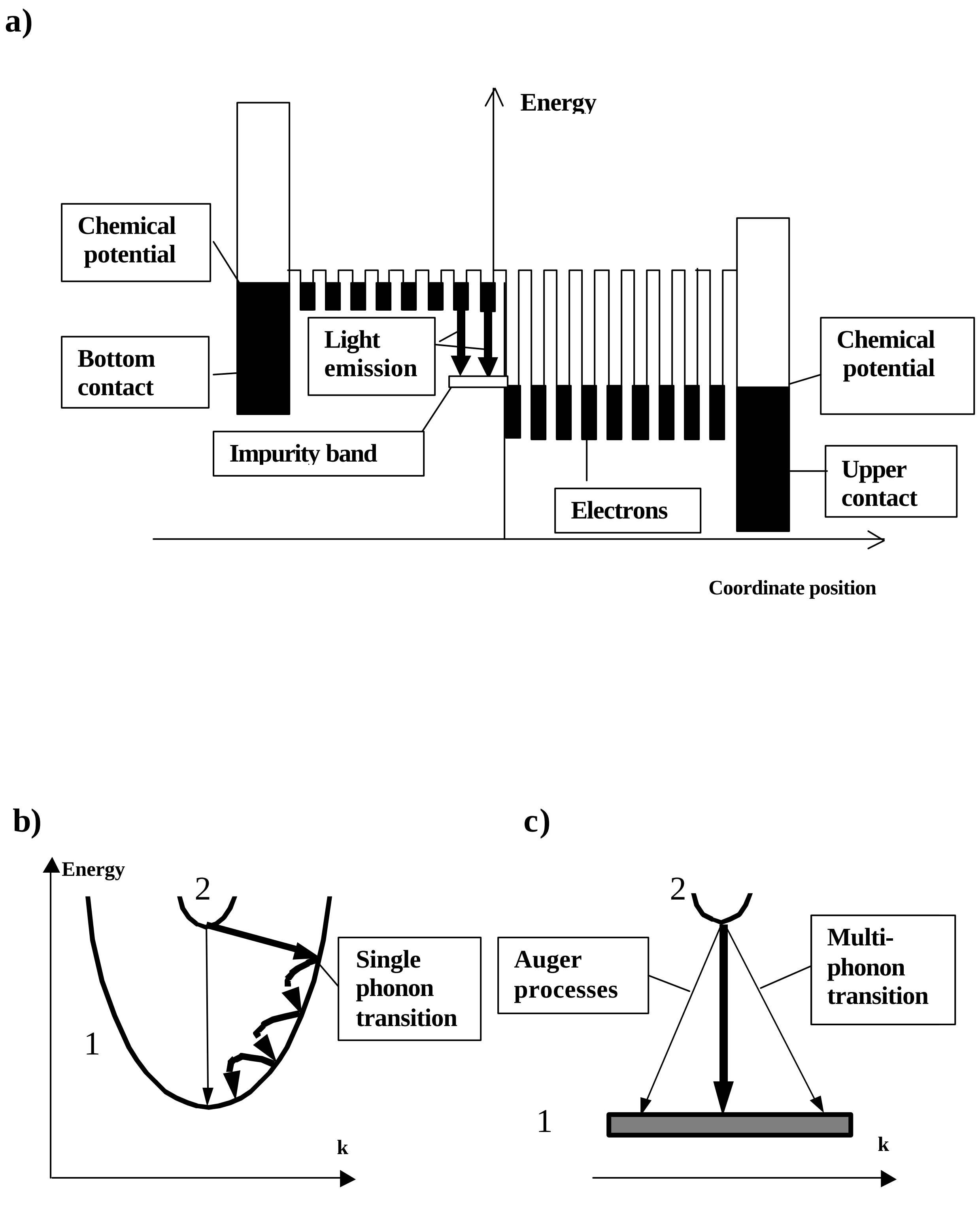

Fig.1. Schematic energy band diagram for the biased U-LED structure with active layer doped with deep acceptors (a). Lateral band diagram of the active layer, made of single square quantum well (b) and of the active layer doped with deep acceptors (c). 1- the lower 2d-subband of quantum well (b) or the impurity 2d-subband (c), 2- the upper 2d-subband of quantum well.