MRS Internet Journal of Nitride Semiconductor Research

Volume 2, Article 19

A Perspective on the GaN Injection Laser

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This article was received on August 4, 1997 and accepted on August 20, 1997.

Abstract

This short paper is a brief review of the problems to be overcome for making an injection laser using a new semiconductor that promises to revolutionize the information storage industry.

1. Memories of the Early Days of Semiconductor Electroluminescence

In l956 I went to France on a David Sarnoff Scholarship. I was fortunate to join Prof. Pierre Aigrain at the Ecole Normale Superieure. Aigrain had just thought of the injection laser and suggested this would be a suitable project for my one year stay in his lab. This was post-war France, however, and the only good piece of equipment was a spectrometer. Device processing was out of the question. I thought I could do some preliminary measurements, learn about spectrometry and then make the laser device when I returned to my lab at RCA. That year was a great experience and I give thanks to my colleague, Benoit-a-la-Guillaume. I learned from him everything I know about spectrometry, a marvelous tool for understanding semiconductors. When I returned to RCA, Management said "the laser idea probably won't work and even if it does, there will be no market for it." That was 1957. In 1962 GE and IBM published their simultaneous papers on the injection laser [1] [2].

This was ten months after I presented a paper on efficient IR emission from a GaAs diode [3]. My manager asked "Who can help you succeed?" "It is too late, we cannot be first now," I answered. Two weeks later I had the same results as IBM and GE, but it *was* too late. The threshold current density of my first diode laser was >10^5 A/cm^2. The diode was cooled in liquid N_2 and energized with 100 ns pulses. It was a dozen years later when a laser diode first worked at room temperature with longer pulses. In l962 I submitted a patent disclosure for a double heterojunction laser. It was judged so crazy that it was made inactive.

2. GaN-based Lasers

Some 30 years later, after dazzling everyone with his blinding blue LEDs, Shuji Nakamura startled the world with the announcement of his blue GaN laser diode that worked at room temperature when excited by a 1 msec pulse [4] [5] [6]. Everyone expected that he should make a CW laser within a few months. However, it took more than ten years before the GaAs laser went CW at room temperature and another ten years to solve the dark line defect degradation.

Let us be patient. The GaN injection laser will become a commercial item within 3 to 5 years. It will be a UV laser rather than a blue laser because the greatest application will be for optical information storage.

In the meantime let us consider the problems that need to be solved. In any laser, the gain must exceed the losses. The major losses are absorption losses. Our studies of photoconductivity (see Figure 1) in GaN revealed that below the Urbach edge at near band-gap photons, there is a long exponential tail extending to at least 1.5 eV. Such a tail suggests an extensive density of states in the bandgap. We found the same characteristic in n-type GaN (even in high mobility material grown by S. DenBaars) and in p-type GaN grown by I. Akasaki's team [7]. Hence the losses must be reduced by further improvement of the material.

There are many radiative transitions in GaN (see Figure 2): free excitons, bound excitons, donor-acceptor pairs, and transitions to deep defects. Of these only the excitons are of interest because they produce a narrow emission line. The threshold current is proportional to the linewidth, which is a measure of the required population inversion. Hence the GaN laser must be designed to stimulate the radiative recombination of free excitons.

However, free excitons are very fragile. They break up in the presence of electric fields as small as 10^4 V/cm. Are there such fields in GaN? From the work of Lester *et al.* [8] we know that Nichia's spectacular blue LEDs have 10^{10} - 10^{11} defects per cm^2. The best device GaN reported to date has ~10^8 defects/cm^2. This corresponds to the defects having on average a spacing of 10^{-4} cm (1μm). The presence of defects and impurities causes local fluctuations of the band edges. These potential fluctuations can vary by more than one Volt. A one Volt change over 1 μm corresponds to an electric field of 10^4 V/cm. This is a field at which the Franz-Keldysh effect occurs causing the tunneling of electrons and the break up of electron-hole pairs that form the needed excitons.

Then why does Nakamura's laser work at all? His laser works because of the clever confinement of excitons inside InGaN wells that are very small compared to one μm. Heterojunction quantum wells had not yet been realized in the early days of the GaAs laser. Hence the major effort in the sixties was devoted to improve the quality of the crystal and to devise clever waveguiding structures.

Having quantum wells is a great advantage, but the quality of the material still must be improved, and later wave guiding and cavity considerations will claim the researchers' attention. Already a serious problem has surfaced: the p-type contact is too resistive. Hence a relatively large voltage bias is required (initially more than 10 V); it causes heating that is minimized by pulsed operation.

Progress is rapid: 12 months after announcing pulsed operation, Nakamura succeeded with CW operation for 35 hours [9]. For commercial applications CW operation must be feasible for at least 20,000 hours. Next the users will want higher power, a shorter wavelength, a cylindrical beam, a surface emitting laser, and modulation at GHz rates. Eventually all these future wishes will be satisfied. However, an enormous amount of work remains to be done -- at least for another 7 ± 2 years.

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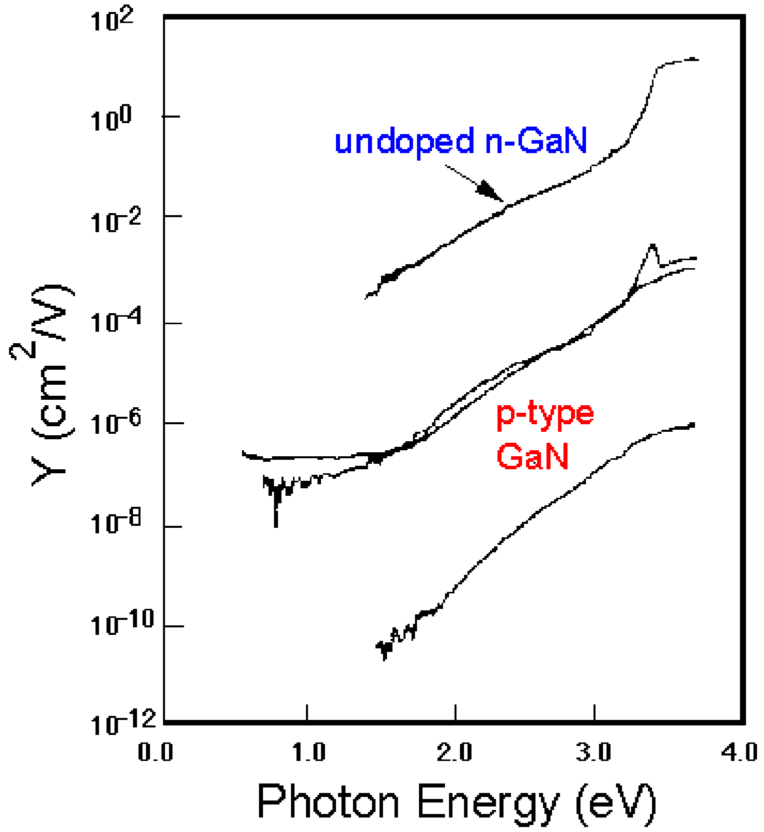

Figure 1. Photoconductivity spectra of several Mg-doped GaN films compared to an undoped n-type GaN sample (data from [5]).

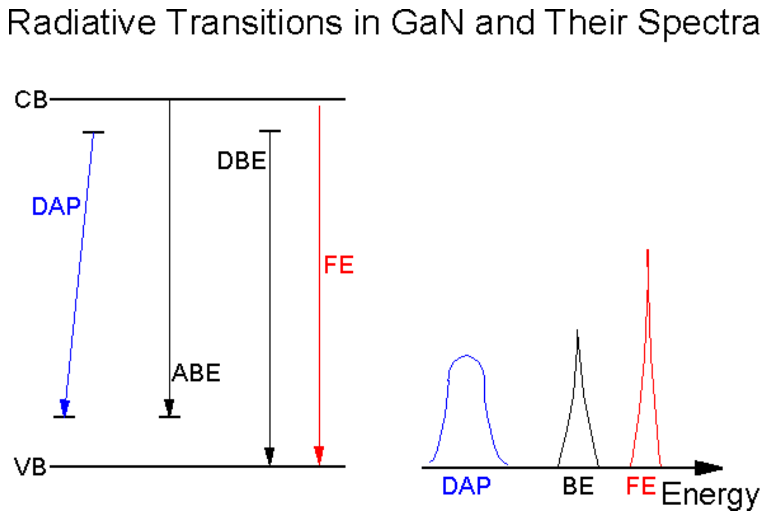

Figure 2. Schematic representation of radiative transitions and their spectra. FE: free exciton, DBE: donor bound exciton, ABE: acceptor bound exciton DAP: donor-acceptor pair.