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This Week's Citation Classic

Lasher G & Stern F. Spontaneous and stimulated recombination radiation in semiconductors. *Phys. Rev. A—Gen. Phys.* **133**:553-63, 1964.
[IBM Thomas J. Watson Research Center, Yorktown Heights, NY]

Spectral line shapes of the radiation produced by the recombination of excess carriers in semiconductors are calculated under the assumption that the momentum matrix element is the same for all initial and final states, i.e., that there is no momentum selection rule. The results are closely related to the temperature dependence of the threshold current in an injection laser. [The *SCI*® indicates that this paper has been cited in over 280 publications since 1964.]

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"In 1962, the first injection lasers were made by Robert Hall and collaborators[1] at the General Electric Research Laboratory and by Marshall Nathan and collaborators[2] at the Thomas J. Watson Research Center. These lasers were gallium arsenide crystals containing a p-n junction. A voltage across the junction caused electrons to flow into the region already containing a high density of holes where they emitted radiation by recombination. If the edges of such a crystal were properly cleaved the resulting optical modes could store enough photons to cause laser emission.

"Here was an elegant little gadget. A tiny crystal and a volt or so of electricity gave coherent radiation. The emitted spectra bore little resemblance to the luminescence spectra of pure semiconductors. The reason was obvious. The carriers in the injection lasers were strongly scattered by the impurities necessary for their operation. We had, however, no good description of the carrier states in the presence of strong scattering. In our conversations we decided to cut this Gordian knot. Why not assume that an electron was equally likely to make a transition to any of the valence band states and ignore the usually important principle of the conservation of crystal momentum? We then derived the necessary equation by applying the theory of radiation to semiconductors with nonequilibrium populations of electrons and holes. The predictions derived therefrom made sense of the observations. We distributed the chores; one of us was awarded the numerical calculations and the other the writing of the manuscript.

"For some time, a large number of people at this and many other laboratories worked on injection lasers. A common aim was to make a device that could operate continuously at room temperature. Gradually the people originally involved found new interests and the development was carried on by a new generation. Today it is gratifying to read about the use of injection lasers in optical fiber systems and in other applications. On the other hand, it was rather surprising to us that these fascinating devices had not found a major practical application much sooner.

"Our paper has been widely cited because it gives the basic theory of a device which has had a long and ultimately successful development. The theory involved some extension beyond the basic physical principles, but it is still simple enough to be useful in interpreting observations. For those wishing to know more about semiconductor lasers, we recommend three recent books."[3-5]

1. **Hall R N, Fenner G E, Kingsley J D, Soltys T J & Carlson R O.** Coherent light emission from GaAs junctions. *Phys. Rev. Lett.* 9:366-8, 1962.
[The *SCI* indicates that this paper has been cited in over 170 publications since 1962.]
2. **Nathan M I, Dumke W P, Burns G, Dill F H, Jr. & Lasher G.** Stimulated emission of radiation from GaAs *p-n* junctions. *Appl. Phys. Lett.* 1:62-4, 1962.
[The *SCI* indicates that this paper has been cited in over 195 publications since 1962.]
3. **Kressel H & Butler J K.** *Heterojunction lasers and heterojunction LEDs.* New York: Academic Press, 1977. 608 p.
4. **Casey H C, Jr. & Panish M B.** *Heterostructure lasers. Part A: fundamental principles.* New York: Academic Press, 1978.
5. **Thompson G H B.** *Physics of semiconductor laser devices.* New York: Wiley, 1980. 549 p.