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Terahertz lasers based on donor intracenter transitions in silicon

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This talk presents a brief overview of terahertz (THz) lasing which is based on the intracenter transitions of impurity Coulomb centers in semiconductors. By now such kind of effects is obtained on group-V donor centers (phosphor P, antimony Sb, arsenic As, bismuth Bi). Energy diagram group-V donor states is shown on Fig.1.

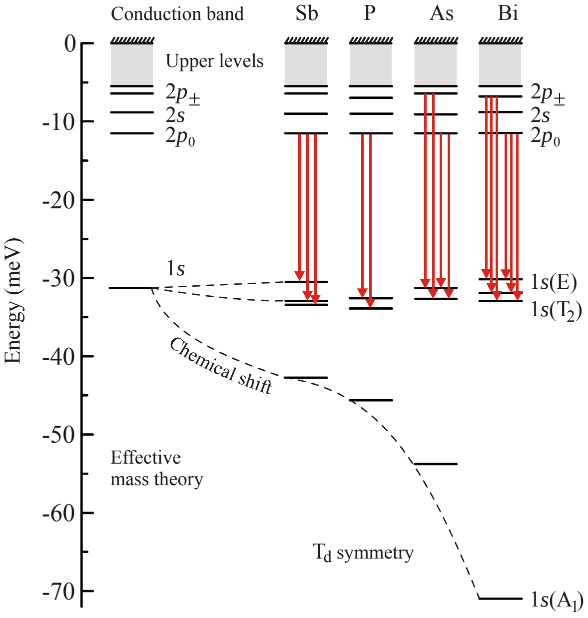

Fig. 1. Energy diagram group-V donor states in silicon. Arrows show possible “normal” laser transitions.

Depending on the pump parameters (frequency, intensity) one can reach either “normal” laser action which develops due to the population inversion between localized donor states or inversionless Raman lasing. Normal lasing occur under optical pumping by a midinfrared laser (for instance by a CO_2 laser) emitting at discrete lines originated from the $2p_0 \rightarrow 1s(T_2)$ and the $2p_\pm \rightarrow 1s(E,T_2)$ transitions subsequently from P, Sb and As, Bi centers in the wavelength range 4,5 – 6,4 THz [1]. Needed population of pointed states are controlled by phonon-assisted relaxation for cryogenic temperatures ($T < 20$ K). Under the same conditions and an intracenter optical excitation of donors one can obtain additionally Raman THz lasing on the transitions between so called “virtual” and 1s(E) final states. As shown the frequency of Raman lasing can be continuously changed between 4,5 – 6,4 THz varying the pump frequency. Normal and Raman lasing of donors were studied using free electron laser FELIX (Netherlands) facility.

Last years the experimental and theoretical activity was focused on the investigation of group-V donor lasing from axially strained silicon crystals. It has been shown that even moderate compressive stress applied along the [100] axis brings to a significant change of THz laser performance of group-V donors [1,2]. There is an optimal strain which may considerably reduce (up to two orders of magnitude) the laser threshold pump intensity increasing small signal gain and efficiency if it concerns normal lasing (see Table1).

Characteristics	Zero stress	Stress along [100] direction
Gain:		
Photo ionization (10,6 μm)	$\leq 0{,}2$ cm^{-1}	*1 cm^{-1}
Intracenter pumping (36 μm)	2–4 cm^{-1}	–
Quantum efficiency:		
Photo ionization (10,6 μm)	*≤1%	*≤10%
Photo ionization (17 μm)	–	*≤15%
Intracenter pumping (19–39 μm)	* 50%	–
Efficiency (10,6 μm):	*up to 10^{-3}	*up to 10^{-2}
Pump threshold (10,6 μm):	≥ 15 – 100 kW/cm^2	≥ 100 – 200 W/cm^2
Frequency tuning:	Absence	Δω/ω~1%
Operating temperature:	< 15 – 30 K	
Donor concentration:	$(2-4)\times10^{15}$ cm^{-3}	
Frequency range:	5,4 – 6,4 THz	

Tab. 1. Characteristics of “normal” THz silicon lasers; * – theoretical estimate.

It is clear that a value of the optimal strain depends on the doping agent. The influence of the axial strain on Raman lasing is still under continuation. The possible mechanisms behind the strain of the host crystal will be discussed.

In conclusion it is worth to touch the issue of another donor centers in the context of THz lasing from silicon.

References

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