Semiconductor Spin-Lasers

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Practical paths to spin-controlled devices are typically limited to magnetoresistive effects, successfully employed for magnetically storing and sensing information, recognized by 2007 Nobel Prize in Physics [1,2]. However, spin-polarized carriers generated in semiconductors by circularly polarized light or electrical injection, can also enhance the performance of lasers, for communications and signal processing [2]. While such spin-lasers already demonstrate a lower threshold current for the lasing operation [3] as compared to their conventional (spin-unpolarized) counterparts, many theoretical challenges remain. Even in the steady-state regime, several surprises have only recently been revealed. For example, we show that a very short spin relaxation time of holes can be advantageous [4], with the maximum threshold reduction larger than what was theoretically thought possible. We analyze dynamical operation of spin-lasers and reveal that the spin modulation can improve their performance. Spin-polarized injection can lead to an enhanced bandwidth [5] and desirable switching properties with reduced chirp [6] which may also enable high-performance spin interconnects [7]. Experimental efforts to increase the temperature of electrically-injected spin-lasers have recently used quantum dots as the active region [8] and we compare their operation to the lasers based on quantum wells [9].

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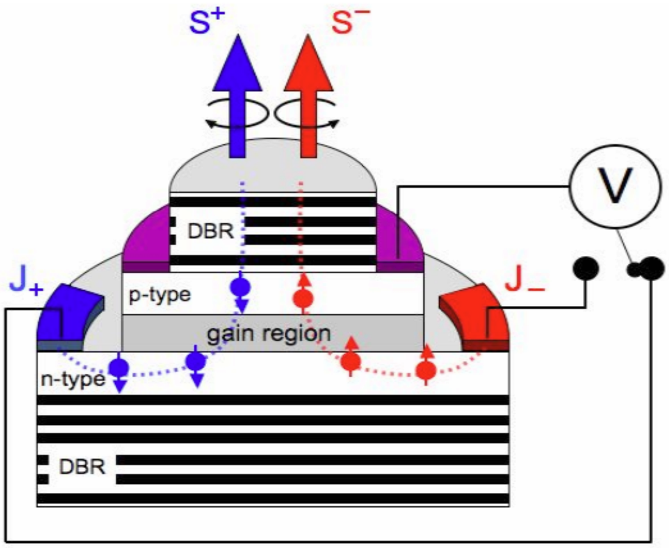

Fig. 1. Spin-laser scheme. The resonant cavity is formed by a pair of parallel highly reflective mirrors made of distributed Bragg reflectors (DBRs) a layered structure with varying refractive index, and the gain (active) region, typically consisting of quantum wells or quantum dots. Electrical spin injection (J_+ different from J_-) is realized using two magnetic contacts. Alternatively, spin-polarized carriers can be injected optically, using circularly polarized light. The recombination of electrons/holes in the gain region, transferred from n- and p-type semiconductors, leads to the emission of coherent light of positive and negative helicity (S^+ and S^-). A spin-laser can act as a spin amplifier: a small spin polarization of the injected carriers can lead to the complete polarization of the emitted light. From J. Sinova and I. Zutic, Nature Mater., in press.

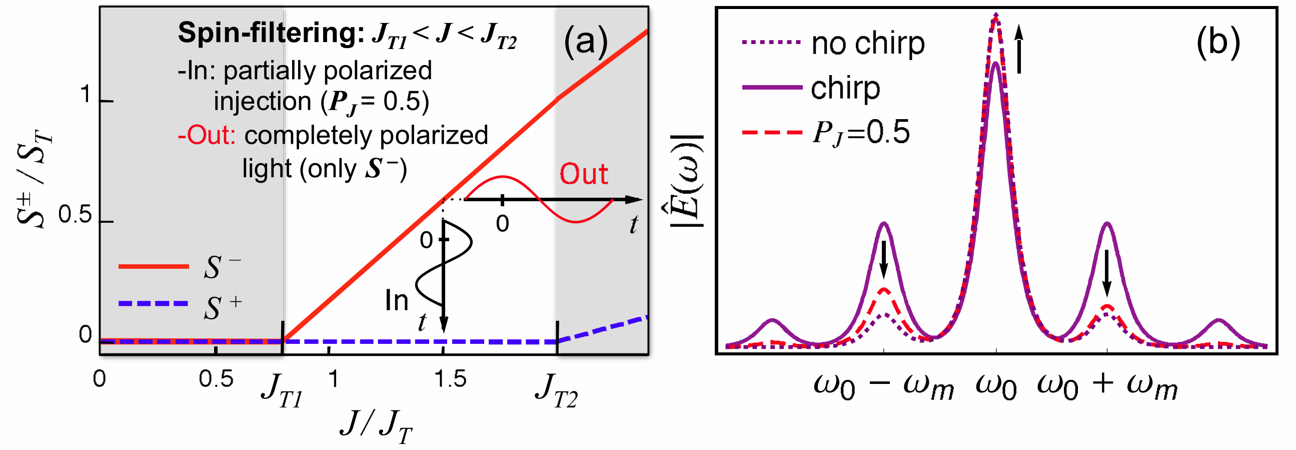

Fig. 2. Amplitude Modulation (AM) and chirp reduction in a spin-laser. (a) Helicity-resolved photon density (S^+, S^-) as a function of injection (J), normalized to $S_T = S(2J_T)$, and unpolarized injection threshold J_T, respectively. For spin-polarized injection, $|P_J| > 0$, there are two thresholds J_{T1}, J_{T2} for S^- , S^+. AM (harmonic curves) for $J_{T1}<J<J_{T2}$ yields modulation of fully polarized light (spin-filtering/amplification, unshaded area). **(b)** Broadened electric field spectrum for AM. Conventional lasers ($P_J > 0$) without (dotted line) and with chirp (solid line), and spin-laser with $P_J > 0.5$ (dashed line) are shown. Arrows indicate the chirp reduction by spin injection. Modulation amplitudes for $P_J = 0.5$ and $P_J=0$ are chosen to provide the same spectra when the chirp is switched off. The choice of colors reflects that an unpolarized S is an equal weight superposition of S^+ and S^-, while for $P_J=0.5$, the emitted light is S^-. From [6].