Surface-acoustic-wave driven planar light-emitting device

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Electroluminescence emission controlled by means of surface acoustic waves (SAWs) in planar light-emitting diodes (pLEDs) is demonstrated. Interdigital transducers for SAW generation were integrated onto pLEDs fabricated following the scheme which we have recently developed [1]. Current-voltage, light-voltage and photoluminescence characteristics are presented at cryogenic temperatures. We argue that this scheme represents a valuable building block for advanced optoelectronic architectures.

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Surface acoustic waves (SAWs) are attracting much interest in semiconductor-device research owing to their interaction properties with quasi two-dimensional systems (2DSs). Lattice deformations induced by SAWs propagating on a piezoelectric substrate (i.e. GaAs) are accompanied by potential waves which interact with charge carriers confined in the heterostructure leading to energy and momentum transfer. This interaction can drag carriers along the SAW-propagation direction resulting in a net DC current or voltage, the acoustoelectric effect [2, 3, 4]. Moreover, this same interaction induces changes in SAW velocity and amplitude that can be used to probe 2DSs transport properties [5, 6, 7, 8].

Several devices were proposed and realized exploiting the acoustoelectric effect. Talyanskii et al. proposed the implementation of a novel current standard based on SAW-driven transport through a quantum point contact [9, 10, 11, 12, 13], demonstrating very precise quantization of the acousto-electric current down to single-electron transfer per wave cycle. A particularly appealing device proposal suggests the incorporation of a single-electron SAW pump in a planar 2D electron/2D hole gas (n-p) junction to realize a single-photon source [14].

In this Letter we demonstrate one of the main building blocks of this latter single-photon source: we shall show transport and optical emission in planar light-emitting n-p devices (pLEDs) controlled by means of SAWs. With the pLED biased below threshold, the electric field associated with SAW propagation in the GaAs facilitates the extraction and transportation of electrons from the n-type region of the structure into the 2D hole gas (2DHG) region, thereby generating electroluminescence emission.

Devices were fabricated starting with a p-type modulation-doped Al$_0.3$Ga$_0.7$As/GaAs heterostructure grown by molecular beam epitaxy, containing a 2DHG within a 20-nm-wide GaAs quantum well embedded 70 nm below the surface. The measured hole density and mobility after illumination at 1.5 K were 2.0 × 10$^{11}$ cm$^{-2}$ and 35000 cm$^{-2}$/Vs, respectively. The heterostructure was processed into mesas with an annealed p-type Au/Zn/Au (5/50/150 nm) Ohmic contact. The fabrication of the n-type region of the junction started with the removal of the Be-doped layer from part of the mesa by means of wet etching (48 s in H$_3$PO$_4$:H$_2$O$_2$:H$_2$O = 3:1:50) and evaporation of a self-aligned Ni/AuGe/Ni/Au (5/107/10/100 nm) n-type contact. After annealing, donors introduced by the n-type contact provide conduction electrons within the well. The n-contact was shaped as a thin stripe placed perpendicular to the SAW-propagation direction, 250 µm away from the p-contact (see Figs. 1a and 1c). SAWs propagating along the (011) crystal direction were generated by means of an interdigital transducer (IDT) composed of 100 pairs of 200 µm-long Al fingers with 3 µm periodicity (≈1 GHz resonance frequency on GaAs). Transducers were fabricated at a distance of 800 µm from the mesa by electron-beam
FIG. 2: (a) Current-voltage characteristics from room temperature down to 5 K. (b) Change of the current (∆I) flowing out of the n-type contact with and without the presence of a SAW as a function of the power of the RF signal applied (P_{RF}) to the IDT at several forward biases around the device threshold (T = 5 K). Inset: Reflectivity of the transducer as a function of the excitation frequency at T = 5 K.

Several pLEDs were fabricated with this protocol and preliminarily electrically tested; all exhibited similar characteristics. Fig. 2(a) shows the current-voltage (I-V) curves at different temperatures of one representative device. A schematic view of the device is shown in Fig. 1b.

The SAW resonance frequency was determined by measuring the change of the current (∆I) flowing out of the n-type contact with (the p-type contact grounded) with and without the presence of a SAW as a function of the power of the RF signal applied (P_{RF}) to the IDT at several forward biases around device threshold (T = 5 K). (See Fig. 2(b)). The RF signal applied to the transducer was set at the measured resonance frequency of 987.5 MHz. ∆I was observed to increase (i.e. more electrons injected into the 2DHG) for biases in the range of 1.6 V to 2.0 V. This regime was observed for values of P_{RF} up to ∼10 dBm. At very high power levels (P_{RF} > ∼10 dBm) a reduction in ∆I is observed probably due to heat losses in the transducer and in the RF cable. These measurements demonstrate that the acoustoelectric effect can enhance the differential conductance of pLEDs near threshold.

SAW control of the junction optical emission was demonstrated by light-bias (L-V) measurements at low temperature (5 K) (see Fig. 3). Spectra as a function of bias were collected by a cooled CCD after spectral filtering by a single-grating monochromator. The electroluminescence (EL) spectra reported in the inset of Fig. 3(b) show a main peak at 818.7 nm (FWHM 1.8 nm) originating from radiative recombination within the QW and a secondary peak at 831.2 nm (FWHM 3.6 nm) which is known to originate from carbon impurities included in the heterostructure material during growth [17]. Furthermore, the SAW can be seen to not change significantly the shape of the spectra.

In conclusion we demonstrated the possibility of controlling the electroluminescence emission from a planar diode by means of surface acoustic waves. Planar junction devices with interdigital transducers were fab-
FIG. 3: (a) Photoluminescence (filled triangles) and electroluminescence intensity as a function of $P_{RF}$ (987.5 MHz) for two different forward voltages (1.8 V empty circles, 2 V empty triangles). Inset: photoluminescence and electroluminescence as a function of the RF-frequency (5 dBm). (b) Light-voltage characteristic of the pLED (filled circles) and the same curve in presence of a SAW (-10 dBm, 987.5 MHz). Inset: electroluminescence spectra at a forward voltage of 2.0 V with a SAW (lower curve, $P_{RF} = -5$ dBm) and without a SAW at $T = 5$ K. The curves are vertically offset for clarity.

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[18] PL spectra were obtained by excitation of a region of the mesa with a red-light laser source (653 nm).