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Microscopic theory of nanoscaled optoelectronic devices

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The impact of optoelectronic technologies on our daily lifes is immense. Via fiber-optical technology, they are used to distribute information over the internet, wether with a PC, a modern smartphone, or to pay by credit card. The key aspect of a rapidly developing discipline, ”Green photonics”, is to reduce power consumption for next generation optical networks, while simultaneously maintaining or improving all other attributes, such as bandwidth, stability and footprint. For such technologies, novel microscopic semiconductor devices will be central components, e.g. for applications in optical communications and data storage.

Among the challenges for the next generation of semiconductor lasers is the enhancement of their modulation speed to satisfy the need for higher data transfer rates. For this purpose, tunnel injection lasers are an appealing concept, as they promise improved modulation rates and better temperature stability. Moreover, they eliminate a major detrimental effect of quantum dot lasers, which is the gain nonlinearity caused by hot carriers. It is shown in this work how the aforementioned improvements depend on the design of tunnel-injection devices. We perform a theory-experiment comparison on scattering times in tunnel injection devices to highlight the importance of alignment between the injector well and the quantum dot ensemble. It is shown how differences in the coupling to the injector quantum well caused by the alignment lead to scattering times into the quantum dot ensemble that vary by an order of magnitude.

Another interesting class of material systems, both for applications and fundamental studies, are atomically thin two-dimensional semiconductors. For opto-electronic applications like displays, light sources, and photovoltaics, transition-metal-dichalcogenides (TMDs) are an appealing system, as they combine great mechanical strength with high carrier mobility and a direct optical band gap. In this rapidly developing field, attention has recently shifted towards the realization of nanostructures.

The generation of localized state, either induced via defects or via systematic confinement engineering, opens the possibility to deterministically generate single-photons or, more generally, provide sources of quantum light. For this purpose, flakes of TMDs have been placed on nanowires, over gold edges and over etched holes to form single-photon emitters. We focus on two different platforms, which are site-selectively generated defects on one hand and TMD nano-bubbles that develop if air is enclosed during the stacking of layers on the other.

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