communications materials

Article

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Activation of telecom emitters in silicon upon ion implantation and ns pulsed laser annealing

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Recent demonstrations of optically active telecom emitters show that silicon is a compelling candidate for solid-state quantum photonic platforms. In particular, the fabrication of a defect known as the G center has been shown in carbon-rich silicon upon conventional thermal annealing. However, the high-yield controlled fabrication of these emitters at the wafer scale still requires the identification of a suitable thermodynamic pathway enabling its activation following ion implantation. Here we demonstrate the activation of G centers in high-purity silicon substrates upon nanosecond pulsed laser annealing. The proposed method enables non-invasive, localized activation of G centers by the supply of short non-stationary pulses, thus overcoming the limitations of conventional rapid thermal annealing related to the structural metastability of the emitters. A finite-element analysis highlights the strong non-stationarity of the technique, offering radically different defect-engineering capabilities with respect to conventional longer thermal treatments, paving the way to the direct and controlled fabrication of emitters embedded in integrated photonic circuits and waveguides.

The G center is a carbon-related point defect in silicon, whose discovery and characterization have surged a strong interest among the scientific community since its recent demonstration as a single-photon emitter[1,2]. In particular, this silicon G center represents an emerging platform in quantum sensing, communication and information processing[3,4], due to several promising features, namely: emission in the telecom range (1279 nm)[5,6]; availability of a triple-singlet transition enabling optically-detected magnetic resonance protocols[7]; appealing coupling of the defect with nuclear spin and electron spin degrees of freedom[3,4,8,9]. Furthermore, its availability as a solid-state color center in silicon without the need for articulated homoepitaxial growth processes paves the way towards the development of highly integrable platforms, upon fabrication by means of industry-compatible techniques such as ion implantation. In this context, the technological capability of introducing G centers in high-purity silicon substrates with a high degree of control will be crucial for the fabrication of practical devices. This goal requires mature ion implantation techniques (e.g. deterministic approaches for the delivery of single impurities with high spatial resolution), as well as highly efficient post-implantation processes enabling their optical activation upon conversion into stable lattice defects[10].

At present, the major obstacle to the systematic implementation of this type of emitter in silicon is represented by its very structural configuration. The point defect has been attributed to a neutrally-charged substitutional dicarbon pair coupled to an interstitial silicon atom[8,11]. This structure, which is rather unusual if compared with that of stable emitters in other classes of materials with diamond-type crystal structure[12–15], poses questions on the existence of suitable pathways for its consistent and efficient fabrication. A relevant concern, recently highlighted in a theoretical study[11], is that the configuration of this complex represents a structurally metastable state, in competition with more stable lattice defects that are energetically more accessible during conventional thermal annealing processes. Indeed, the formation of the G center requires the occurrence of two separate processes, namely: the accommodation of a C atoms at a substitutional lattice site and its interaction with a mobile C interstitial[11]. In this respect, it is worth remarking that, while the former process is enhanced by the thermal treatment of the substrate[9], the latter one is unfavored by annealing treatments and rather promoted by radiation-induced damage within the crystal[11]. This observation is in line with the experimental results reported so far in the literature. The production of the G center has been typically

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