A bright nanowire single photon source

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Abstract: Silicon-vacancy (SiV) centers in diamond are bright sources of indistinguishable single photons. We report fabrication of nanowires coupled to single SiV by deterministic ion implantation, yielding greatly enhanced light coupling compared to SiV in bulk.

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1. Introduction

The negatively-charged silicon-vacancy (SiV^-) center in diamond consists of an interstitial Si atom between two vacancies in the carbon lattice (Fig.1-inset). It is a bright source of indistinguishable single photons with many potential applications in quantum information and communication [1]. Unfortunately, due to the high refraction index mismatch between diamond and air, color centers in diamond show low photon out-coupling. Fabricating nano-structures around these color centers can increase their optical coupling and enable quantum photonics applications. Here we report fabrication of monolithical nanowires coupled to single SiV^- centers created by deterministic Silicon ion implantation, and demonstrate an increase in photon count rate by at least a factor three with respect to defects in bulk diamond.

2. Methods

We employed a top-down procedure to produce a large array of nanowires [2] in a HPHT-diamond sample via electron-beam lithography and reactive-ion etching (RIE) techniques (Fig.1). Then we deterministically implanted Silicon ions in the nanowires by using focus ion beam techniques (FIB) and finally obtained the creation of single SiV^- centers embedded in the nanowires by annealing the sample. To characterize the SiV^- we measured non-classical light emission using a home-built confocal microscope and a 50 : 50 fiber splitter. In correspondence to the lower dose implantations, we observed an antibunching dip (Fig.2.a), the signature of single photon emitters, as confirmed by fitting the data with the model discussed in [3].The great benefits of coupling SiV^- to the nanowires can be observed by the comparison between the count rate from an individual SiV^- embedded in the nanowire Fig.2(c) and an ensemble of SiV^- in a bulk crystal Fig.2(b). We measured the count rate of the photons emitted by single

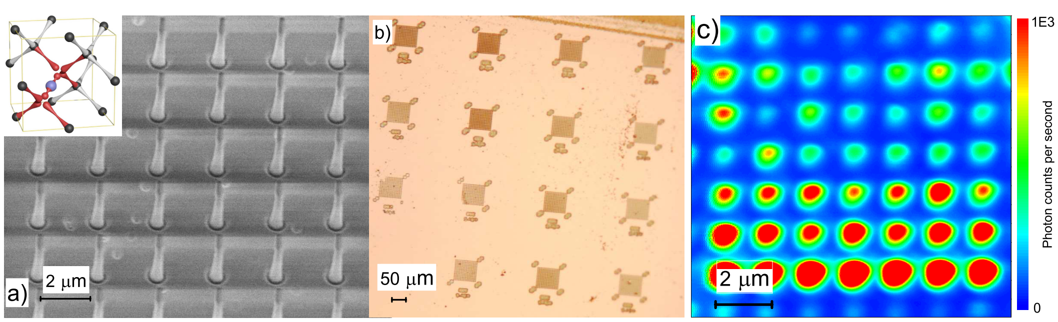

Fig. 1. **Nanowires containing SiV color centers (a)**, Secondary electron emission image of a typical array of nanowires made for this experiment on a different diamond, **(inset)** atomic structure of a SiV color center. **(b)** Optical images of the nanowires array. **(c)** Confocal microscopy scan $(15\times15\mu m^2)$ of the nanowires array after SiV creation. The first three rows of the array contains multiple SiV centers (~ 10), while other rows contains single or double SiV. The image clearly shows a correlation between the number of Si ions implanted and the number of SiV created.

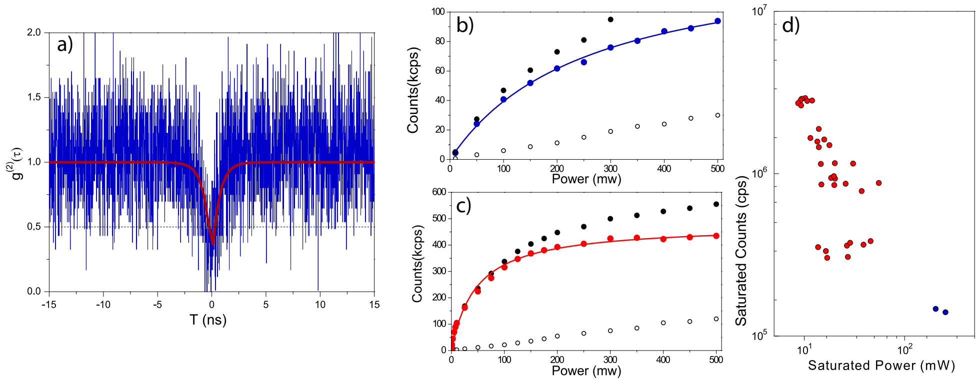

Fig. 2. **Characterization of single SiV centers in nanowires. (a)** Second order autocorrelation function $g^{(2)}(\tau)$ fitting of the raw coincidence rate of the light coming from the single SiV in the nanowire taken at $P_{Laser} = 1mW$. Fluorescence rate of a small ensemble of SiV in bulk diamond **(b)** and for a single SiV center in a nanowire **(c)** as function of the pump power. Black circles indicate raw counts from the bulk **(b)** and from the nanowire **(c)**, hollow circles indicate the linear background and filled circles show the normalized SiV counts. **(d)** Distribution of the properties (P_{sat} and I_{sat})) for each nanowire in the array (red circles) compared to ensemble of SiV in the bulk (blue).

SiV^- inside the nanowire as function of the power of the excitation laser applied. As shown in Fig.2(c), after a rise at low pump powers($P < P_{sat}$) the count intensity saturates($I = I_{sat}$) at high power ($P > P_{sat}$), as expected [4]. The measured single SiV^- saturation intensity is three times higher than for ensembles of SiV^- in bulk, while thanks to the nanowire effects, the single photon emitter get pumped at least five times more efficiently. We remark that these results underestimate the nanowire coupling efficiencies, since we could not find single SiV^- in the bulk diamond in our sample and the comparison is made with a small ensemble of emitters.

3. Conclusions

We deterministically implanted single SiV^- in nanowires fabricated in diamond, and we verified that SiV^- in the nanowires are single photon sources by performing second order correlation measurement. We also demonstrated an improvement in the photonics coupling of single SiV^- due to presence of the nanowire. SiV^- in nanowires are pumped at least five times more efficiently than SiV^- in the bulk and allow at least three times higher single photon count rate. This result will enable a new class of devices for integrated photonics and quantum information processing.

4. Acknowledgements

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References

1. L.J.Rogers, K.D.Jahnke, T.Teraji, L.Marseglia, C.Muller, B.Naydenov, H.Schauffert, C.Kranz, C.Isoya, L.P.McGuinness, and F.Jelezko. Multiple intrinsically identical single-photon emitters in the solid state. *Nature Communications*, 5:4739, 2014.
2. T.M. Babinec, B.J.M. Hausmann, M.Khan, Y.Zhang, J.R. Maze, P.R. Hemmer, and M. Lon*č*ar. A diamond nanowire single-photon source. *Nature Nanotechnology*, 5:1038, 2010.
3. A.Beveratos, S.K*ü*hn, R.Brouri, T.Gacoin, J.-P.Poizat, and P.Grangier. Room temperature stable single-photon source. *The European Physical Journal D*, 18:191–196, 2002.
4. C. Kurtsiefer, S. Mayer, P. Zarda, and H. Weinfurter. Stable solid-state source of single photons. *Nature Nanotechnology*, 85(2), 2000.