Bulk diamond optical waveguides fabricated by focused femtosecond laser pulses

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ABSTRACT

Diamond's nitrogen-vacancy (NV) centers show great promise in sensing applications and quantum computing due to their long electron spin coherence time and their ability to be located, manipulated and read out using light. The electrons of the NV center, largely localized at the vacancy site, combine to form a spin triplet, which can be polarized with 532-nm laser light, even at room temperature. The NV's states are isolated from environmental perturbations making their spin coherence comparable to trapped ions. An important breakthrough would be in connecting, using waveguides, multiple diamond NVs together optically. However, the inertness of diamond is a significant hurdle for the fabrication of integrated optics similar to those that revolutionized silicon photonics. In this work we show the possibility of buried waveguide fabrication in diamond, enabled by focused femtosecond high repetition rate laser pulses. We use μRaman spectroscopy to gain better insight into the structure and refractive index profile of the optical waveguides.

Keywords: femtosecond laser, laser microfabrication, NV center, diamond, optical waveguide, quantum optics

1. INTRODUCTION

Diamond shows remarkable beauty when cut appropriately, making it the best friend a significant percentage of the population. Scientists instead are excited about diamond for a completely different reason. Although many think of diamond as the perfect material, there is actually a defect, the so-called nitrogen vacancy center, which could be used as the building block of advanced quantum computing platforms or ultrasensitive and nanoscale resolution magnetic field sensors. The magic of the nitrogen-vacancy (NV) center, in which a nitrogen sits next to an empty site in the carbon lattice, is that it is an optically active spin defect having a very long room temperature spin coherence time.

Due to diamond's inertness, it has proven difficult do develop an integrated optics platform which could optically link NV centers for magnetomery and quantum information applications [1], [2]. Recently, femtosecond laser microfabrication was proposed to enable a 3D photonics toolkit for diamond [3], [4]. Since focused femtosecond laser pulses damage the crystalline lattice [5], an indirect approach was used: optical mode confinement was achieved between two closely spaced and parallel laser-inscribed modification tracks.

In this work, we discuss the mechanisms for waveguiding using this type II fabrication method and provide better insight into the role the repetition rate. We demonstrate for the first time the fabrication of optical waveguides in ultrapure diamond which could address single NV centers in quantum information systems. In addition, we show shallow waveguide formation in the less pure optical grade diamond, of relevance for high resolution ultrasensitive magnetometry.

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Laser 3D Manufacturing IV, edited by Bo Gu, Henry Helvajian, Alberto Piqué,
Corey M. Dunsky, Jian Liu, Proc. of SPIE Vol. 10095, 100950Q · © 2017 SPIE
CCC code: 0277-786X/17/$18 · doi: 10.1117/12.2258062