

Nanoparticle Gratings for Compact Spectrometers: an Application of Photovoltaic Tweezers

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Abstract. Compact spectrometers are useful in fiber-based setups, portable devices or systems where weight and space are limited. On the other side, Photovoltaic Tweezers (PVT) are a simple and flexible optoelectronic technique for patterning and trapping nano- and microobjects in accordance with arbitrary light profiles. In this work, Al nanoparticle (NP) gratings assembled by PVT have been used for the fabrication of SWIFTS-based and dispersive spectrometers. A method for transferring the NP structures has been successfully adapted to deposit these gratings on top of Ti-diffused LiNbO₃ waveguides (WG) without a significant loss of quality; the successful transference of NP patterns to arbitrary substrates remarkably extends the potential applications of PVT.

1. Introduction

Integrated optical spectrometers are an excellent option for reducing weight and power consumption in interferometric devices. Additionally, the almost total absence of moving parts provides high robustness and improved stability [1]. In fact, since integrated systems use to be intrinsically compact, they are a perfect option for applications in which weight and space are limited and/or the system undergoes severe vibrations or forces. These applications include portable devices or aerial spectroscopy systems set on unmanned aerial vehicles (UAV) and satellites [2].

Compact spectrometers are mainly classified in two groups: Fourier transform-based (or SWIFTS) and dispersive ones. The former family encompass those devices in which an interferogram is generated inside a waveguide (WG) and then it is sampled by scattering points placed on the WG surface. The spectrum is recovered using a Fourier Transform algorithm. The second group also confines the input light in a WG but they use a surface diffraction grating and relay optics to directly obtain the signal spectrum on a detector [1].

In this work, nanoparticle (NP) gratings assembled by Photovoltaic Tweezers (PVT) have been used for the fabrication of both kind of compact spectrometers. PVT are an emergent, flexible optoelectronic technique for patterning and manipulation of nano- and micro-objects in accordance with arbitrary light profiles [3]. It takes advantage of the evanescent electric fields that appear in photorefractive crystals with high bulk photovoltaic effect, like LiNbO₃:Fe, when they are suitably illuminated. PVT have proven to be a useful tool for controlled arrangement of bio-objects, making diffractive optical elements or producing plasmonic platforms.

2. Devices fabrication

In order to fabricate these devices, a series of Al NP linear gratings with different periods and fill factors were patterned via PVT. This was a two-step process. First, X- and Z-cut LiNbO₃:Fe crystals were illuminated with a two Gaussian beam interference in order to obtain the appropriate space-charge distribution. Afterwards, the crystals were introduced in a hexane suspension with the Al NP, which



settled on the crystals surface making up fringes. Depending on the spectrometer configuration, NP strips were designed to be sparse and so, behave just as scattering centers (SWIFTS), or as fully dense linear diffraction gratings (dispersive).

These NP patterns were transferred on top of LiNbO₃ samples with several Y-junctions Ti-diffused WG fabricated on its surface. This process was carried out following a method close to the one described in [4]. There was not a significant loss of quality between original and transferred patterns.

3. Spectrometers characterization

Regarding SWIFTS, the sample was attached to an optical bench consisting in a light detector and a Michelson interferometer. Two He-Ne laser beams, each coming from one arm of the interferometer, were injected in the Y-junction WG. The stationary wave was obtained by simple Fresnel reflection at the WG output. Scattered intensity of a single NP cluster was recorded as a function of the optical path delay, obtained by displacement of the mirror on one of the interferometer arms. We were thus able to detect the beams interference (see Figure 1a). However, we were unable to find the interferogram corresponding to a polychromatic light source due the combination of the wavepacket dispersion inside the WG, the reduced contrast of fringes in a SWIFTS configuration using simple Fresnel reflection and the large size of the scattering center.

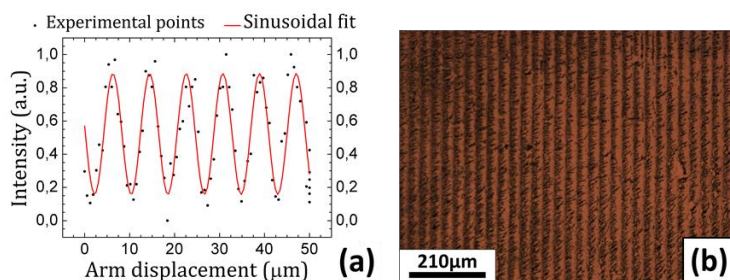


Figure 1. a) Scattering intensity of a single NP cluster as a function of the displacement of one of the Michelson arms. **b)** Al NP grating (period 30 μm) transferred on a LiNbO₃ WG.

For the characterization of the dispersive spectrometer, a 1.5 μm infrared laser source was employed. The key elements of the setup were a pair of mirrors, a cylindrical lens to collect the light extracted from the WG and a detector. The laser beam was divided using the mirrors and again injected in a Y-junction WG. The NP grating deposited on this sample was considerably thicker than the previous one (see Figure 1b) and it worked as a proper linear diffraction grating. Light was extracted from each arm of the Y-junction WG, collected by the lens and its interference recorded with the detector. Successful results were obtained, although the presence of different modes in the WG and defects in the NP grating affected negatively to the signal profile.

4. Future perspectives

This work presents one of the first practical applications of PVT. Although the first results are not as good as the current state of the art, they are promising and expected to be improved by decreasing the size of the scattering centers. The fabrication of compact spectrometers by PVT has the advantage of being much faster than conventional methods such as focused ion beam (FIB) or Au-NP deposition. In addition, gratings made by PVT are easily reconfigurable, which means the WG can be reused. Finally, the successful transference of high-quality NP patterns to arbitrary substrates is a notable advance itself, as it remarkably broadens the potential applications of PVT.

Acknowledgments

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