# Enhancing the 3rd order nonlinear optical response of integrated micro-ring resonators with graphene oxide 2D films

**David Moss** ( dmoss@swin.edu.au )
Swinburne University of Technology

**Research Article**

**Keywords:** nonlinear optics, integrated photonics, silicon, graphene oxide, Kerr nonlinearity

**Posted Date:** June 14th, 2021

**DOI:** https://doi.org/10.21203/rs.3.rs-617143/v1

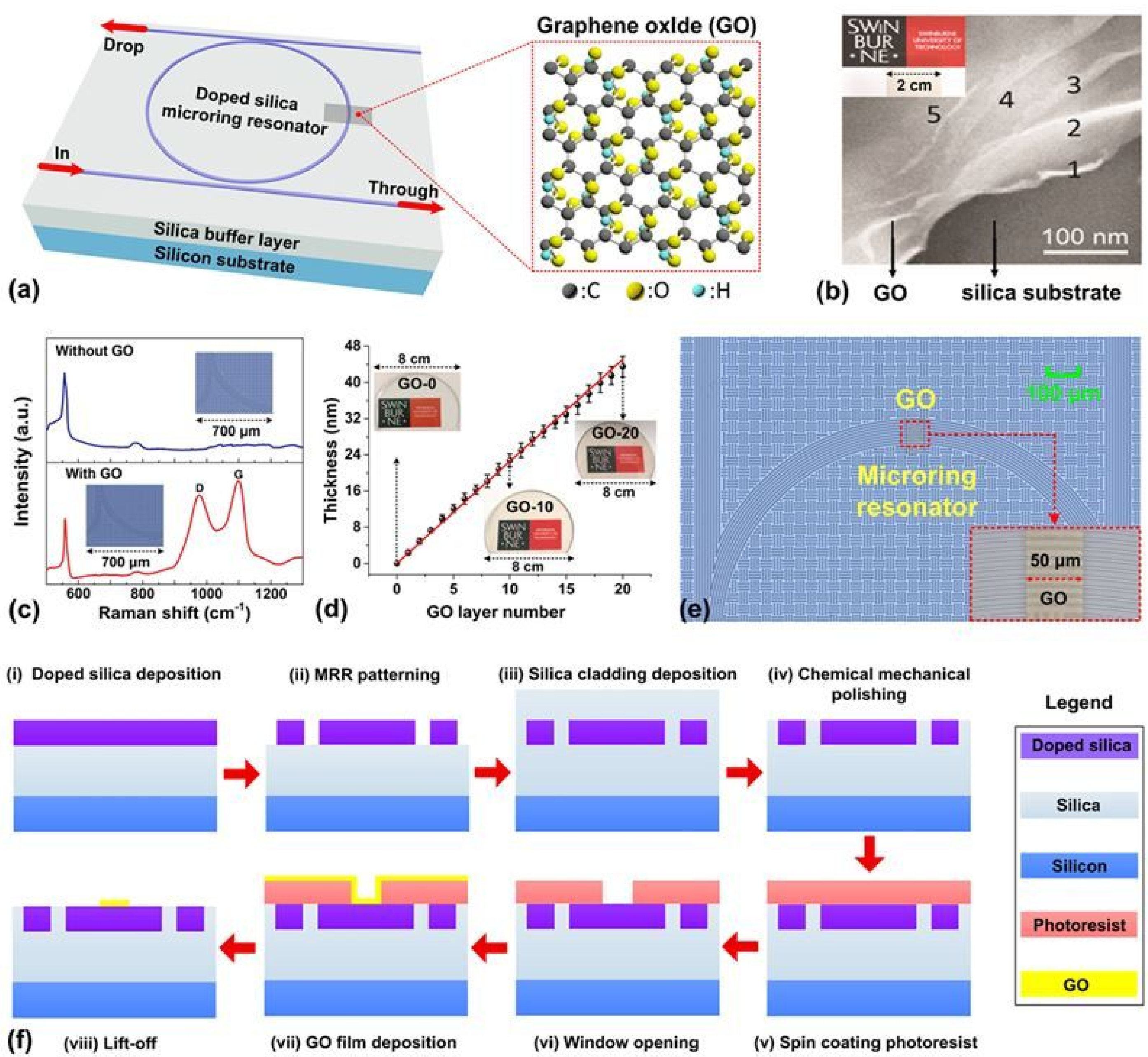
## Abstract

Layered two-dimensional (2D) graphene oxide (GO) films are integrated with micro-ring resonators (MRRs) to experimentally demonstrate enhanced nonlinear optics in the form of four-wave mixing (FWM). Both uniformly coated and patterned GO films are integrated on CMOS-compatible doped silica MRRs using a large-area, transfer-free, layer-by-layer GO coating method together with photolithography and lift-off processes, yielding precise control of the film thickness, placement, and coating length. The high Kerr nonlinearity and low loss of the GO films combined with the strong light-matter interaction within the MRRs results in a significant improvement in the FWM efficiency in the hybrid MRRs. Detailed FWM measurements are performed at different pump powers and resonant wavelengths for the uniformly coated MRRs with 1 – 5 layers of GO as well as the patterned devices with 10 – 50 layers of GO. The experimental results show good agreement with theory, achieving up to ~ 7.6-dB enhancement in the FWM conversion efficiency (CE) for an MRR uniformly coated with 1 layer of GO and ~ 10.3-dB for a patterned device with 50 layers of GO. By fitting the measured CE as a function of pump power for devices with different numbers of GO layers, we also extract the dependence of GO's third-order nonlinearity on layer number and pump power, revealing interesting physical insights about the evolution of the layered GO films from 2D monolayers to quasi bulk-like behavior. These results confirm the high nonlinear optical performance of integrated photonic resonators incorporated with 2D layered GO films.


## Full Text

This preprint is available for download as a PDF.

## Figures




## Figure 1

(a) Schematic illustration of GO-coated integrated MRR. Inset shows schematic atomic structure of GO. (b) Scanning electron microscope (SEM) image of 2D layered GO film. The numbers 1–5 refer to the number of GO layers for that part of the image. Inset shows 5 layers of GO on a silica substrate. (c) Raman spectra of an integrated chip without GO and with 2 layers of GO. Insets show the corresponding microscope images. (d) Measured GO film thickness versus GO layer number. Insets show the images of a silica circular substrate uniformly coated with 0 (uncoated), 10, and 20 layers of GO. (e) Microscopic image of an integrated MRR patterned with 50 layers of GO. Inset shows zoom-in view of the patterned GO film. (f) Schematic illustration showing the fabrication process flow for an integrated MRR with patterned GO film.

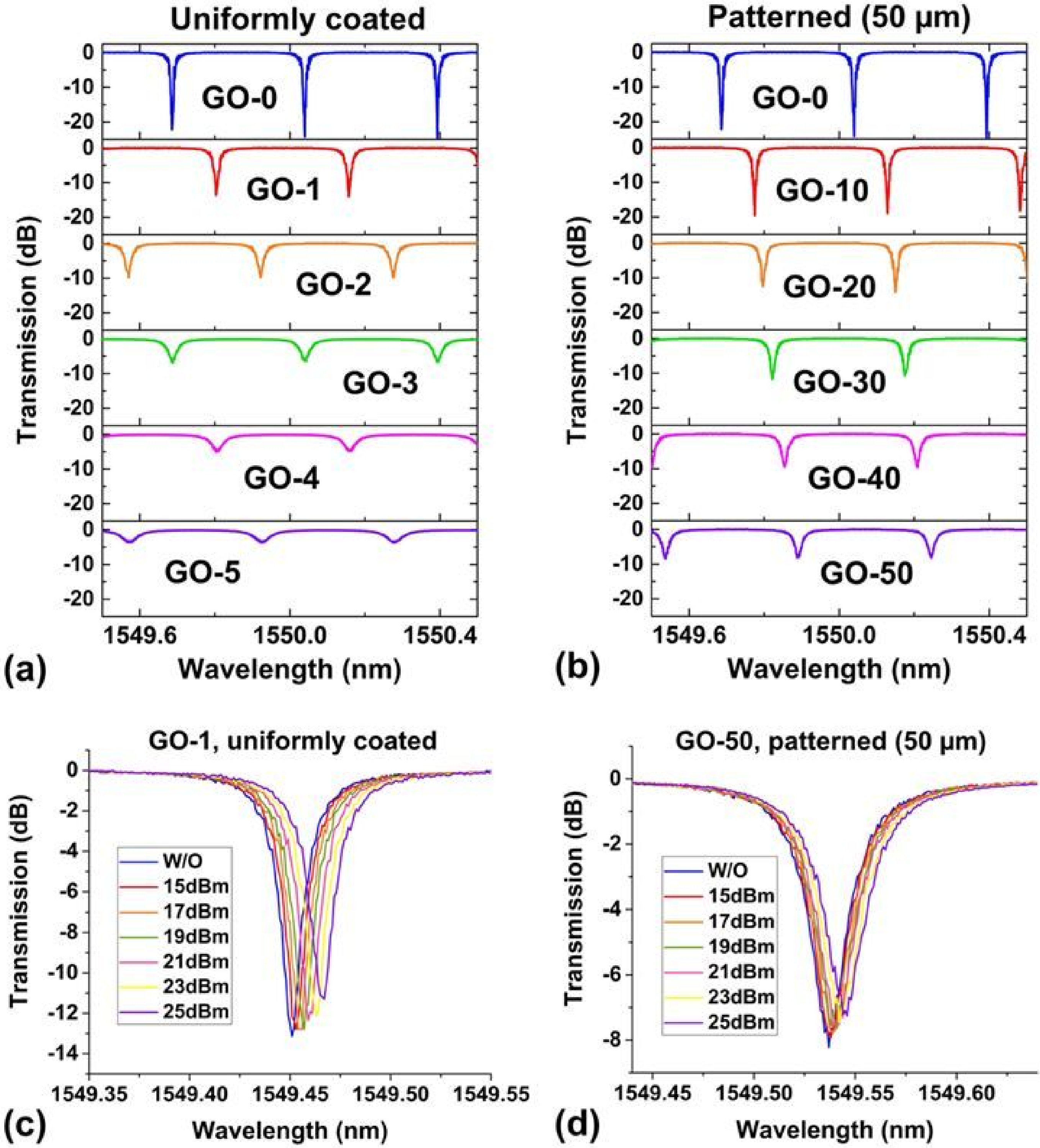
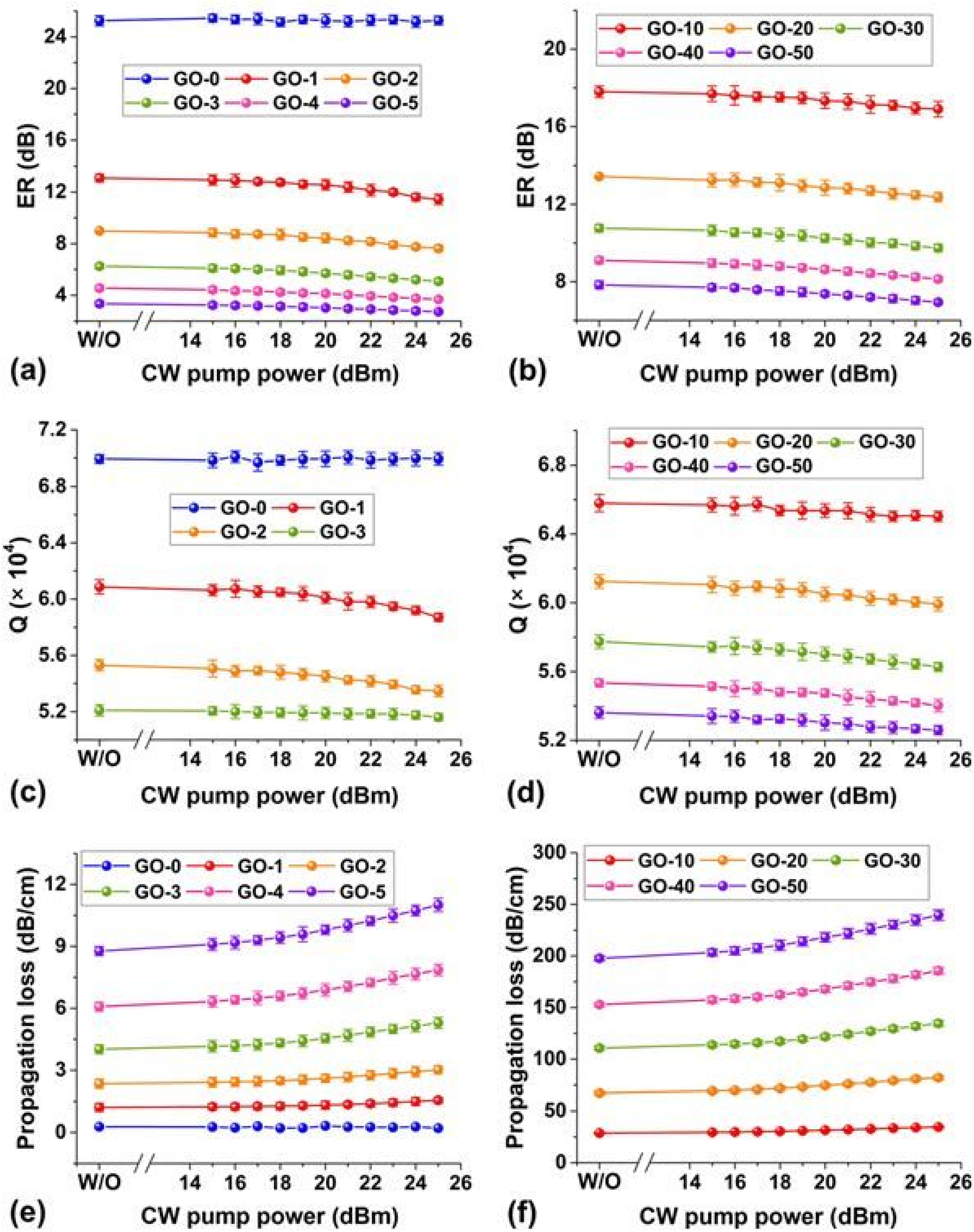



**Figure 2**

(a)−(b) Transmission spectra of an integrated MRR uniformly coated with 1−5 layers of GO and patterned with 10−50 layers of GO measured using a low-power CW light, respectively. The measured transmission spectrum of the uncoated MRR (GO-0) is also shown for comparison. (c)−(d) Transmission spectra of the MRRs with 1 layer of uniformly coated and 50 layers of patterned GO measured using a low-power CW probe when another high-power CW pump was injected into a resonance around 1550.18 nm,

respectively. The values of 15–25 dBm represent the incident pump powers. The transmission spectra measured using the low-power CW probe without the high-power CW pump (W/O) are also shown for comparison.




## Figure 3

Power dependent (a)–(b) extinction ratios (ERs) and (c)–(d) quality factors (Qs) for the MRRs with 1–5 layers of uniformly coated and 10–50 layers of patterned GO films, respectively. The ERs and Qs of the

uncoated MRR (GO-0) are also shown for comparison. The Qs are not shown when the ERs are < 5 dB. (e)−(f) Fit propagation loss obtained from (a)−(d), respectively. The values of 15−25 dBm represent the incident pump powers. The data points for W/O correspond to the values measured using a low-power CW probe without the high-power CW pump.

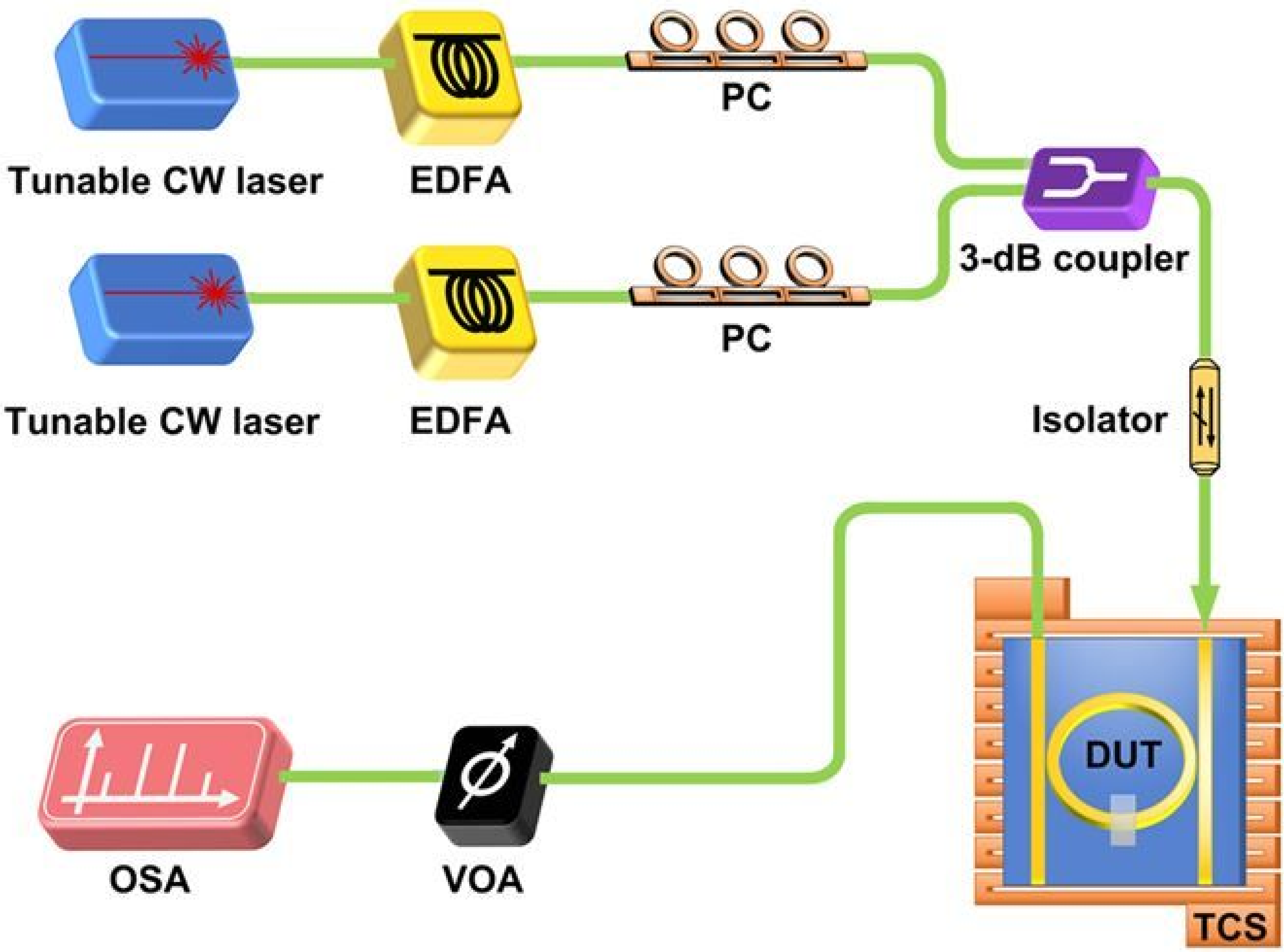
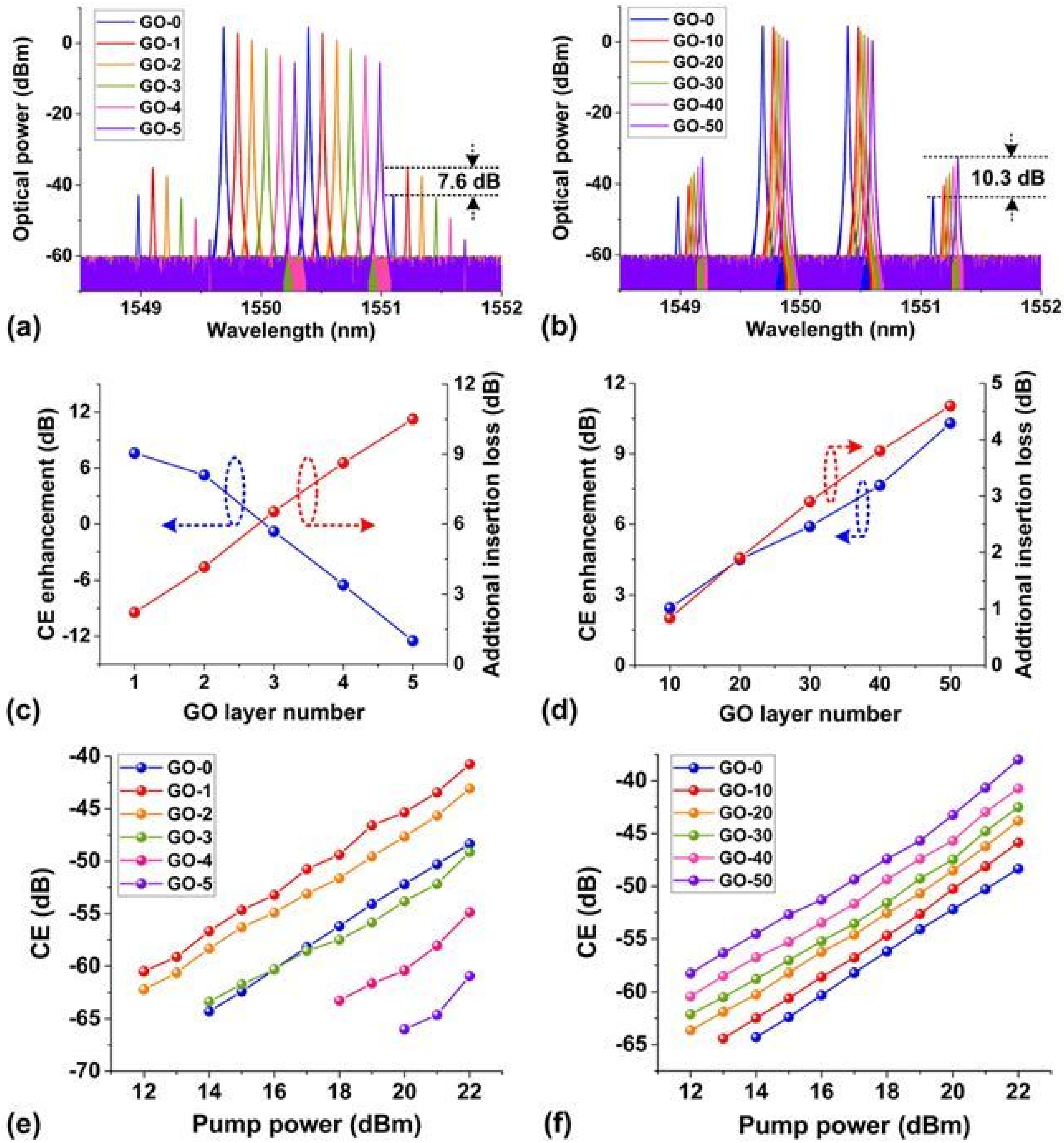


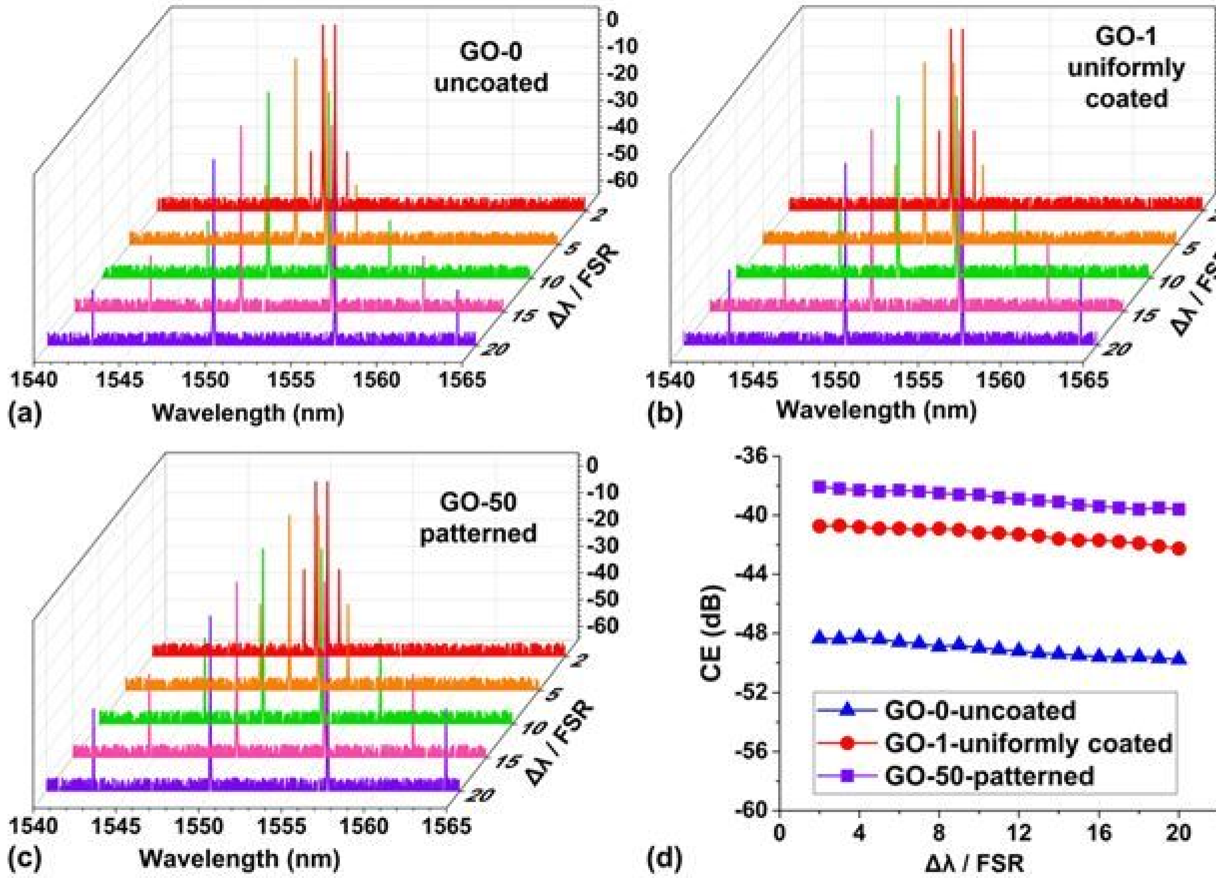

**Figure 4**

Experimental setup for FWM measurements in integrated MRRs. EDFA: erbium-doped fiber amplifier. PC: polarization controller. DUT: device under test. TCS: temperature controller stage. VOA: variable optical attenuator. OSA: optical spectrum analyzer.



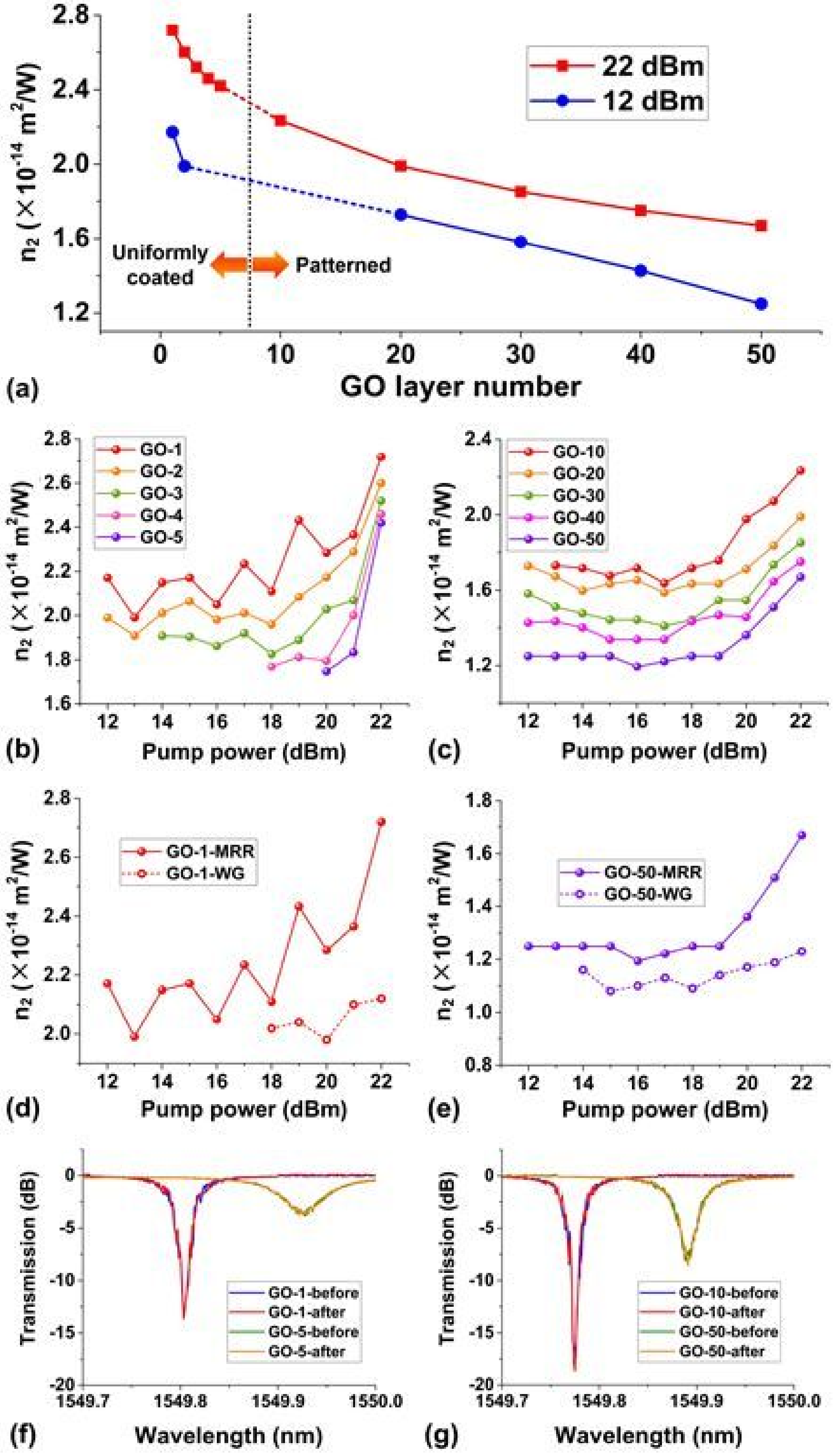

## Figure 5

(a)–(b) Optical spectra of FWM at a pump power of 22 dBm for the MRRs with 1–5 layers of uniformly coated and 10–50 layers of patterned GO films, respectively. (c)–(d) CE enhancement and additional insertion loss extracted from (a) and (b), respectively. (e)–(f) CE versus pump power for the MRRs with 1–5 layers of uniformly coated and 10–50 layers of patterned GO films, respectively. In (a), (b), (e), and (f), the results for uncoated MRR (GO-0) are also shown for comparison.




## Figure 6

(a)−(c) Optical spectra of FWM at different resonant wavelengths for the uncoated MRR, the MRR uniformly coated with 1 layer of GO, and the MRR patterned with 50 layers of GO, respectively. Δλ and FSR represent the wavelength spacing between pump and signal and the free spectral ranges of the MRRs, respectively. (d) Measured CE versus Δλ/FSR for the MRRs in (a)−(c). The pump power in (a)−(d) was 22 dBm.




## Figure 7

Analyses of the change of GO material properties during the FWM process. (a) n2 of GO versus layer number at fixed pump powers of 12 dBm and 22 dBm obtained from the MRR FWM experiment. (b)–(c) n2 of GO versus pump power for 1–5 layers and 10–50 layers of GO obtained from the MRR FWM experiment, respectively. (d)–(e) n2 of GO versus pump power (1 layer of GO in (d) and 50 layers of GO in (e)) obtained from the MRR and waveguide (WG) FWM experiments. (f)–(g) Measured transmission

spectra of GO-coated MRRs (uniformly coated with 1 and 5 layers of GO in (f) and patterned with 10 and 50 layers of GO in (g)) before and after FWM with a pump power of 22 dBm.