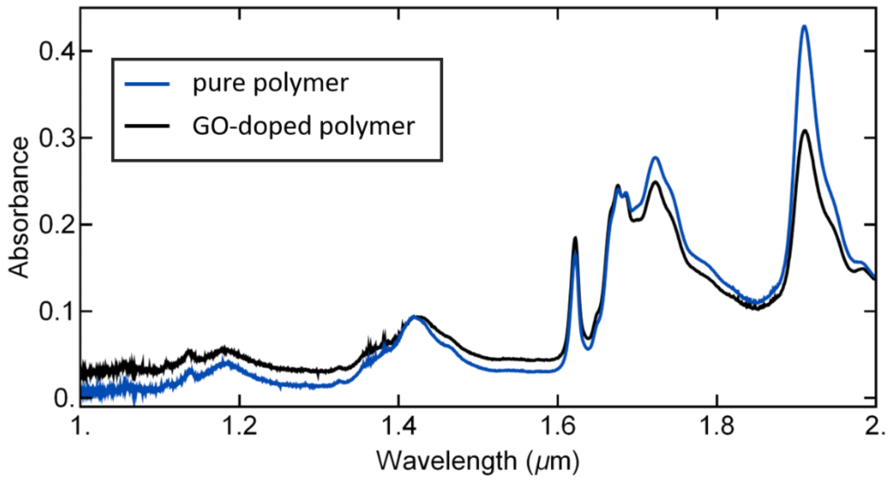
Supplementary material

Paper: ‘Mode cleaning in graphene oxide-doped polymeric whispering gallery mode microresonators’, published at the Journal of Material Chemistry C (2020)

1- Absorbance spectrum for the acrylate polymer and for the GO-doped polymer in the near infrared:



For this analysis, the macroscopic samples were prepared as described in the experimental section of the paper.

2- Comparative table of values for the resonances indicated in the spectrum:

The contribution of material attenuation to the intrinsic Q-factor was calculated through:

$$Q_{mat} = \frac{2\,\pi\,n}{\lambda_0 \alpha}, \tag{1}$$

where n, λ_0 and α denote the refractive index, the resonance wavelength and the material attenuation coefficient, respectively. The material attenuation coefficient for each resonance was obtained from absorbance measurements, as described in the paper.

The dependence of the intrinsic Q-factor (Q_{in}) with the Q-factors associated with material attenuation (Q_{mat}) and surface scattering ($Q_{s.s.}$) is given by:

$$\frac{1}{Q_{in}} = \frac{1}{Q_{mat}} + \frac{1}{Q_{s.s.}}. \qquad (2)$$

Q_{in} determines the photon lifetime associated with intrinsic losses (τ_0) according to:

$$\tau_0 = \frac{2\, Q_{in}}{\omega_0}. \qquad (3)$$

The transmission response of the straight waveguide coupled to the microresonator at the frequency ω is given by:

$$T(\omega) = T_0 \frac{(\omega - \omega_0)^2 + \left(\frac{1}{\tau_0} - \frac{1}{\tau_c}\right)^2}{(\omega - \omega_0)^2 + \left(\frac{\Delta\omega}{2}\right)^2}, \qquad (4)$$

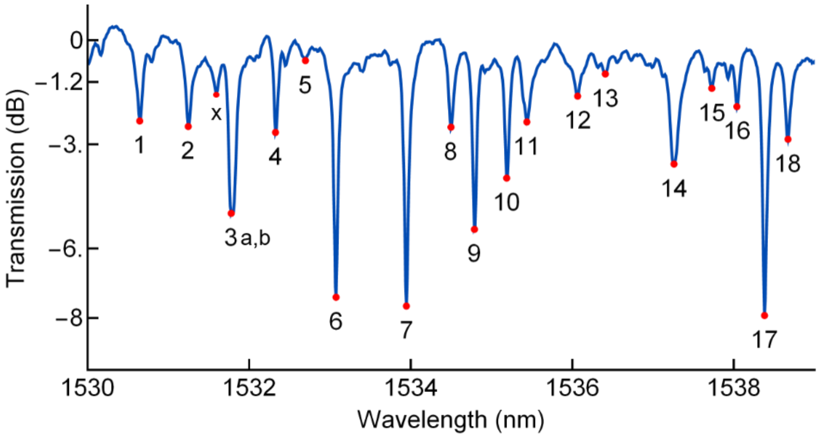
which includes a sigmoid function to capture the asymmetry of the resonances:

$$\Delta\omega = \frac{4\left(\frac{1}{\tau_0} + \frac{1}{\tau_c}\right)}{1 + \exp\left[\alpha(\omega - \omega_0)\right]}. \qquad (5)$$

In the Eq. 4 and 5, T_0 is an offset correction factor, ω_0 is the resonance frequency, α is the asymmetry factor and τ_0 and τ_c are the lifetimes associated with power dissipation through intrinsic losses in the microresonator and through coupling losses, respectively.

The values represented in the following tables were obtained by calculating Q_{mat} with the help of Eq. 1, and by fitting each resonance to Eq. 4. E.R. stands for the resonance extinction ratio.

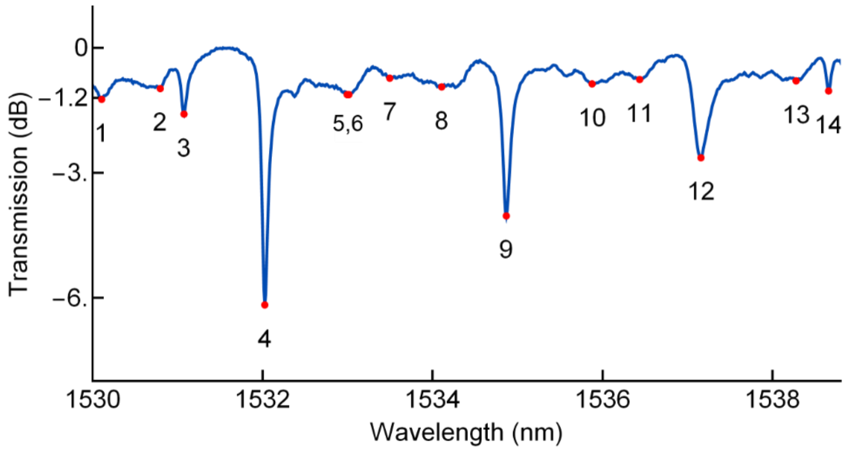
Undoped microresonator spectrum:



resonance	linewidth in pm	E. R.	asymmetry factor in ps	$1/\tau_0$ in ns^{-1}	$1/\tau_c$ in ns^{-1}	$Q_{s.s.}$	Q_{mat}
1	120	0.472	0	41.6	6.6	16000	193700
2	108	0.456	2.4	37.7	5.7	17800	193600
x	95	0.21	0	36.0	2.1	18710	193600
3a	98	0.61	0	32.0	7.4	21370	193600
3b	53	0.49	0	18.3	3.0	40700	193600
4	77	0.495	5.1	26.4	4.5	26400	193500
6	86	0.805	3.4	24.8	9.7	28370	193400
7	96	0.826	3.4	27.2	11.3	25600	193300
8	99	0.445	6.2	34.6	5.0	19440	193200
9	82	0.722	0	24.9	7.8	28200	193200
10	89	0.604	0	28.8	6.7	23900	193100
11	150	0.390	2.2	53.5	6.5	12190	193100
12	126	0.303	0	46.1	4.2	14270	193000
14	174	0.548	0.4	58.0	11.7	11180	192900
15	110	0.275	0	40.6	3.2	16380	192800
16	81	0.332	0	29.4	2.8	23350	192800
17	103	0.836	3.4	28.8	12.2	23900	192700
18	96	0.429	1.8	33.5	4.7	20160	192700

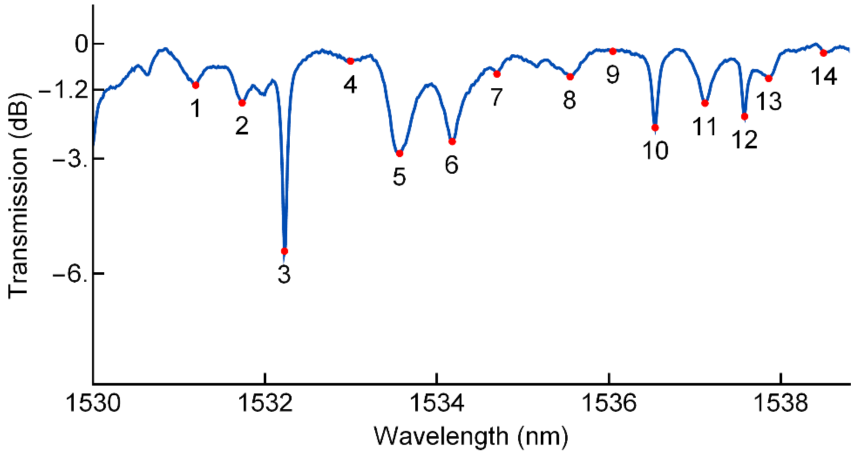
GO-doped microresonator spectrum:

For Polarization 1:



resonance	linewidth in pm	E. R.	asymmetry factor in ps	$1/\tau_0$ in ns^{-1}	$1/\tau_c$ in ns^{-1}	$Q_{s.s.}$	Q_{mat}
4	134	0.758	6	38.9	14.8	19840	77400
9	133	0.577	2.2	44.1	9.1	16990	77300
12	268	0.454	2.2	92.9	13.9	7210	77200
14	70	0.183	0.8	26.5	1.3	32970	77100
16	218	0.163	0.1	82.9	3.7	8157	77000

For Polarization 2:



resonance	linewidth in pm	E. R.	asymmetry factor in ps	$1/\tau_0$ in ns^{-1}	$1/\tau_c$ in ns^{-1}	$Q_{s.s.}$	Q_{mat}
3	102	0.694	0	31.8	9.1	25790	77400
6	300	0.412	0	105.9	14.2	6270	77300
10	94	0.372	0	33.6	3.9	23890	77200
11	223	0.275	0.5	82.3	6.6	8240	77200

The impact of the incorporation of GO on each resonance's linewidth and extinction ratio was evaluated through the variation of its transmission curve in response to an increase of intrinsic losses. For that, we adjusted the material attenuation and the surface scattering contribution to the Q-factor of each individual resonance to match both Q_{mat} and the $Q_{s.s.}$ that are expected with the incorporation of GO to the microresonator.

Let us take the resonances 17 and 18 of the undoped microresonator spectrum as an example. Their $Q_{s.s.}$ and Q_{mat} are:

resonance	$Q_{s.s.}$	Q_{mat}
17	23900	192700
18	20160	192700

To simulate the presence of GO, the $Q_{s.s.}$ of the resonances 17 and 18 was adjusted to 19840 and to 8240, and their Q_{mat} was adjusted to 77400 and 77200, respectively. By doing that, the resonances transmission curve resulted in the black curve of the graph below.