# Compact spectrometer: Breaking the resolution limit by taking advantage of photonic crystal randomness by deep learning

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Optical spectrometer has been used in different fields, but they usually consist of gratings, which makes the device bulky. If we use nanophotonic technologies, we should be able to miniaturize the device. Indeed, there has been some trials to use structures such as photonic crystals (PhC), but the operation usually relies on complex resonant structures. Here, we propose and demonstrate compact spectrometer based on simple chirped PhC waveguide (WG) structure.

Since the mode-gap frequency of a PhC-WG is dependent to the width [Fig. 1(b)], we can design a spectrometer by using a chirped PhC-WG [Fig. 1(a)]. When light enters into a chirped PhC-WG it scatters out from the slab when it reaches the WG at the mode-gap. We fabricated the device by using standard silicon photonics fabrication techniques to operate the device in between 1565 to 1585 nm. When we input single wavelength laser light, we observed clear difference in the far-field image [Fig. 1(c)]. We can know the wavelength of the input light from the location where the light is scattered.

However, there remains problems. In particular, only coarse wavelength resolution (1.5 nm) is achieved due to the fabrication resolution limit. So the question is: *can we beat this resolution limit?*

It is known that a fabricated PhC-WG exhibits Anderson localization of light, when the input light frequency is close at the mode-gap. The localization occurs randomly, due to the fabrication error, and the near-field pattern are sensitive to the frequency of input light as shown in Fig. 1(d). By taking advantage of this phenomena, we should be able to increase the frequency resolution. In order to reconstruct the spectrum information from the acquired camera image, we need to have a calibration image database, since the localization pattern changes randomly. Therefore, we built a database by inputting single wavelength laser light and employ deep learning algorithm [Fig. 1(e)]. We expect to successfully reconstruct the spectrum information by feeding the algorithm with training images and testing it with a test image set.

Figure 1(f) shows the training process of the software when we increase the number of learning iteration over the training set. We trained the software with 0.2 nm resolution dataset, which is higher than the designed wavelength resolution of the device (1.5 nm). Due to the random localization, the picture of the light pattern in the waveguide is slightly different when the wavelength is changed, though the difference is so small to distinguish for human. However, the accuracy rises up to 95%, which shows that the deep learning algorithm is capable to distinguish these wavelengths. We even managed to reach 0.1 nm resolution by using two neural networks in tandem. The details of the algorithm will be presented in the talk.

In summary, we demonstrated that a chirped PhC-WG allows us to obtain high wavelength resolution when we use deep learning algorithm. We demonstrated that our deep learning program can detect single frequencies between 1565 nm and 1585 nm with an outstanding 0.2 nm resolution.

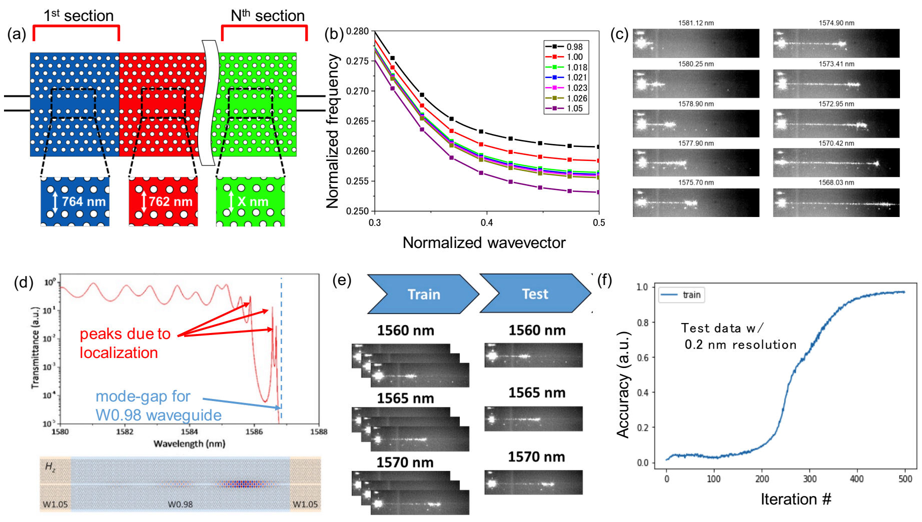


Fig. 1 (a) Chirped PhC-WG to enable spectrometer operation. (b) Mode-gap frequencies for different wavelength width. (c) Acquired camera image from top of the slab when different wavelength is input from the left. (d) Anderson localization of light close at the mode-gap frequency. (e) Schematic illustration of the deep-learning algorithm. (f) Learning curve of the deep learning with 0.2-nm resolution datasets.