The conventional spectrometers rely on one-to-one spectral-to-spatial mapping. Such mapping is necessary for a wavelength demultiplexer but not a spectrometer. Complex spectral to spatial mapping has been explored with disordered photonic crystals, thin scattering media, and random polychromat, for spectrometer application. The disorder-induced scattering of light produces wavelength-dependent speckle patterns which can be used as fingerprints to identify unknown spectra. We recently utilized multiple scattering of light in a random photonic chip to build a compact on-chip spectrometer. The probe signal diffuses through a scattering medium generating wavelength-dependent speckle patterns which are used to recover the input spectrum after calibration. In contrast to single scattering or diffraction from a thin disordered material that gives a linear scaling of spectral resolution with dimension $L$, the multiple scattering in a lossless diffusive medium makes the scaling quadratic, thus the resolution increases more rapidly with $L$. By fabricating the scattering structure on-chip, we can efficiently channel the scattered light to the detectors and engineer the disordered medium to reduce out-of-plane scattering. We obtain sub-nanometer (0.75 nm) resolution (at a wavelength of 1500 nm) with a very small (25 µm radius) footprint [1].

A multimode fiber also generates speckle via interference among the guided modes. The output speckle pattern is unique for each wavelength, thus can be used to identify the spectral content of input light [2]. The spectral resolution scales with the fiber length [3]. Since optical fibers have been optimized for long-distance transmission with minimal loss, long fibers can be used to provide fine resolution without sacrificing sensitivity. We have reached a record resolution of 1 pm at a wavelength of 1500 nm using a 100-meter long multimode fiber, outperforming the state-of-the-art grating spectrometers [4]. In addition, the fiber spectrometer can simultaneously measure many spectral channels, thanks to the mapping from one-dimensional spectrum to two-dimensional (real) space. We have achieved broad-band operation with a 4 cm long fiber, covering the wavelength range of 400 nm – 750 nm with 1 nm resolution. The fiber spectrometer, consisting of the fiber which can be coiled to a small volume and a monochrome camera that records the speckle pattern, is compact, lightweight, and low cost. By integrating a wavelength division multiplexer with five multimode optical fibers, we have overcome the trade-off between spectral resolution and bandwidth [5]. An efficient algorithm is developed to achieve accurate reconstruction of both sparse and dense spectra in the presence of noise.