A New Weak Light Detection Technique: Reduction of Scattered Light and Ghosts in a Raman Spectrum by a Frequency Discriminating Optical Chopper

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A new technique is described which reduces unwanted scattered light and ghosts in Raman spectra. For a perfectly constructed system, the Rayleigh component will be zero, and only the Raman spectra will be detected. This method is far superior to the conventional lock-in, electron counting, and noise power Raman detection techniques.

Introduction

In the study of the Raman effect from elementary excitations, coupled modes, and single particles, it is necessary to investigate the Raman spectrum for frequencies less than 200 cm^{-1} and at low light levels of less than 10^{-5} I Rayleigh.[1,2] The problem of scattered light and ghosts (Rowland, Lyman, satellites, and grass) arising from both single and double grating spectrometers[3] often hampers the detection and discrimination of Raman lines.

A new detection method has been developed which could be used with a single or double spectrometer to reduce scattered light and eliminate ghosts from the Raman spectrum. This technique is highly selective in that the Raman spectrum is chopped and phase detected while the Rayleigh scattering, unwanted scattered light, and ghosts are not.

Method

The new Raman detection system, shown in Fig. 1, depends primarily on a new type of light chopper combined with a spectrometer, photomultiplier, lock-in detection, and a strip chart recorder. This chopper referred to here as a frequency discriminating optical chopper (FDOC) consists of half of a spike filter centered at the laser frequency and half of a neutral density filter. The transmission of the neutral density filter is matched to the peak transmission of the spike filter. The transmission matching can be made better than 0.1%. Since the peak of the spike filter depends on the angle of incidence of the light, a collimated beam should pass through the chopper, as shown in Fig. 1(b). It is necessary for the operation of the device that the half-width of the spike filter be greater than the Rayleigh or laser half-widths, typically a few angstroms.

The filter combination can consist of either circular disks or square plates held together by an aluminum frame. The filters are oscillated by a synchronous motor in a reciprocating or rotary motion. The reference signal is supplied optically.

The stages of operation of the new FDOC detection system are shown in Fig. 2. In the first stage, the scattered light from the sample before entering the chopper consists of Raman and Rayleigh scattering (including Brillouin). In stage 2, the scattered light is passed through the chopper. While the chopper is oscillating, the Rayleigh light passes through the spike filter, and the Raman and Rayleigh light pass through the neutral density filter. The important point here is that the Raman spectra is chopped while the Rayleigh is not. It is the unchopped Rayleigh scattering that produces the unwanted scattering and ghosts in the spectrometer. This is shown in stage 3. The lock-in[4] rectifies and averages the chopped ac portion of the signal (Raman spectrum) which was mixed with the reference signal. The average output of the lock-in is shown in stage 4. For an ideal transmission matching of the spike and neutral density filters, the output signal is the Raman spectrum. Because the transmission of the filters cannot be exactly matched, a small portion of the Rayleigh line appears typically 10^{-3} of the Rayleigh line. The subtraction of large signals as the laser frequency is approached results in a slight increase is the shot noise.[4] Care should be taken not to saturate the PMT.[5]

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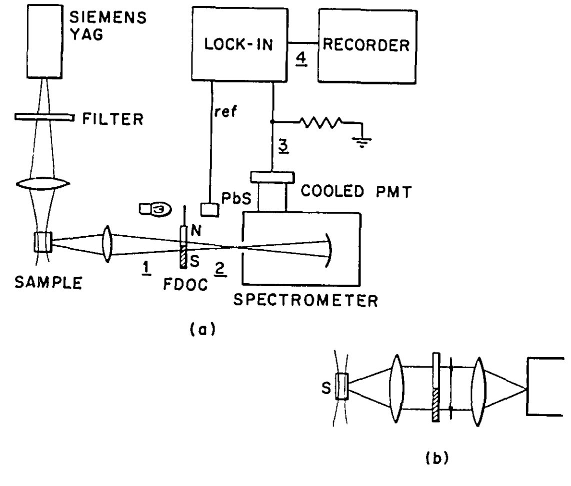

Fig. 1. New Raman light detection technique.

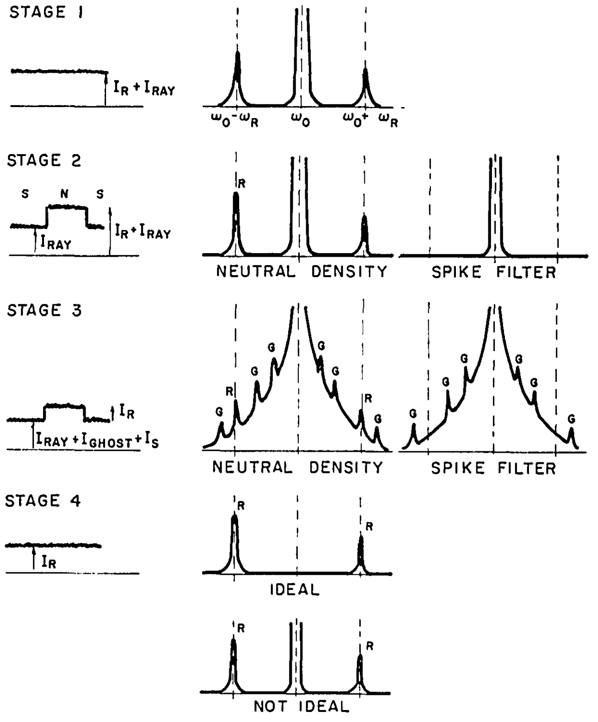

Fig. 2. Schematic representation of the operation stages of the FDOC technique.

The new chopper could also be incorporated with an electron counting scheme but the advantage over the lock-in is slight.[4] A well-known technique[6,7] of reducing the Rayleigh intensity is to employ a spike filter in reflection instead of in transmission. The reflected and transmission of light from a spike filter is shown in Fig. 3(a). The reflected Rayleigh from the filter is reduced, typically by 20% while the Raman spectrum is totally reflected. Combining the reflection mode of an array of spike filters with the FDOC device gives added discrimination against the Rayleigh intensity to $\sim 3 \times 10^{-6}$ for the device shown in Fig. 3(b).

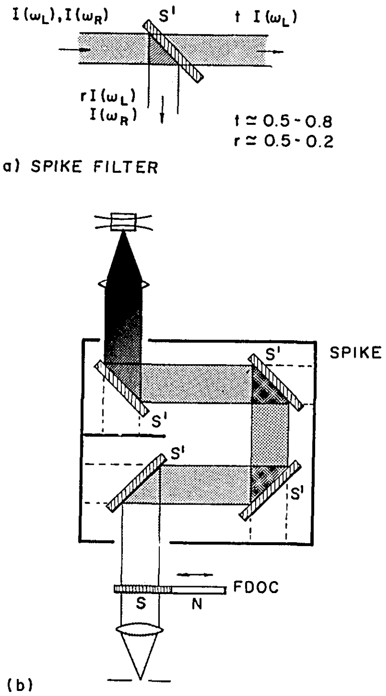

Fig. 3. A reflecting spike filter used as a light discriminator. (a) Transmission and reflection from a spike filter at an oblique angle of incidence. r = reflection coefficient, t = transmission coefficient. (b) Combined system of reflecting spike filters and FDOC device.

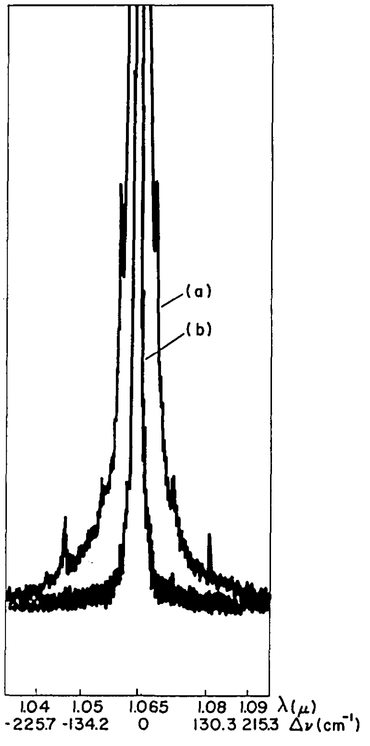

Fig. 4. Discrimination against ghosts and scattered light. (a) Conventional lock-in. (b) FDOC lock-in.

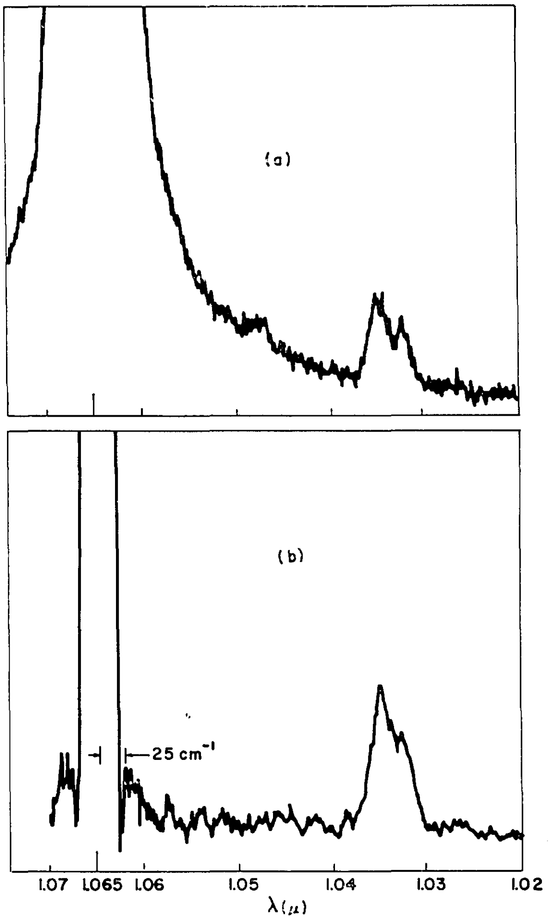

Fig. 5. Comparison of conventional lock-in and FDOC detection for Raman lines in GaAs. (a) Conventional lock-in, G = 0.2, T = 3 sec, slit width = 250 μ. (b) FDOC lock-in, G = 1.0, T = 10 sec, slit width 250 μ.

Experiment

The experimental arrangement, shown in Fig. 1, consists of a Siemens YAG laser, 0.5-m, Jarrell-Ash single spectrometer, equipped with 600 lines/m grating blazed at 1 μ, a cooled RCA 7102 PMT, a PAR JB-5 lock-in, and a recorder. The spike filter used in the device has a half-width of 50 Å and a transmission of 48.5% at 1.065 μ.

We have compared the conventional lock-in technique with the new FDOC method for ghost and scattered light discrimination. Figure 4 shows the detected scattered light off a scattering plate using first the conventional lock-in and then the FDOC detection technique. Ghosts and scattering wings are readily noticeable in the conventional lock-in detection [Fig. 4(a)], while the FDOC detection reduces the wings and eliminates the ghosts [Fig. 4(b)]. The Rayleigh line in Fig. 4(b) is due to the imperfect matching of the filters. The rate of the Rayleigh line for the lock-in to the FDOC detection was over 300. A reduction of over 10^3 could be obtained with a better match in the filters.

Figure 5 shows the detected Raman scattering from the optical phonons in semiinsulating GaAs using the conventional and FDOC lock-in detection. The FDOC detection reduces the scattered light as shown in Fig. 5(b) enabling the spectra as close as 25 cm^{-1} to be examined, while the conventional lock-in, Fig. 5(a), obscured the Raman spectrum in this region. A reciprocating type of chopper was utilized in the above experiments.

The FDOC device is both inexpensive and simple to construct. When a single spectrometer is utilized with an FDOC device, results similar to a double spectrometer are obtained. A comparison of the signals-to-noise ratio for the FDOC lock-in, and electron counting is in progress.

My appreciation is extended to N. Yurlina for constructing the FDOC device, to G. J. Spellman for suggesting the use of an array of spike filters and alternate designs of the FDOC device, and to D. H. Baird and N. Ockman for helpful discussions, and to the referee who informed me of the existence of a similar technique.[8]

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High Index Fiber Optics Core Glass

A fiber optic core glass claimed to have a very high refractive index (1.805) without excessive coloration has been developed by the British company Chance-Pilkington, St. Asaph, North Wales. Its properties, essential for converting the glass into high quality fibers, have been incorporated without making the price prohibitive. Combining sufficiently high viscosity for drawing fibers and a low liquidus temperature, it is compatible with Chance-Pilkington's ME1 fiber optic cladding glass. This has necessitated critical control of expansion and softening points of FOC1 glass so that a perfect seal to ME1 glass can be achieved, thus reducing the problem of making finished faceplates vacuum tight. The thermal expansion for FOC1 glass is 68×10^{-7} (0–300°C) and softening point 799°C. Chance-Pilkington claim the numerical aperture of a fiber clad with ME1 glass is 1, so each fiber collects light over a 180°-field. The new glass is supplied in extruded slabs made by Chance-Pilkington's EM process which was brought into operation last year. The process, combining the repeatability of pot melting with the relatively low operating cost of continuous manufacture, is now used to make a variety of the more sophisticated optical and technical glass types.

ASPHERIC LENS HELPS HOME JET

A new aspheric lens system has been produced by Combined Optical Industries Limited, Slough, U.K., to help give an instant fix in aircraft navigation—demonstrated dramatically in the transatlantic race-winning RAF Harrier's precise mid-city landings in London and New York, and soon to be installed in civil aircraft. The lens is incorporated in the Automatic Chart Display (ACD) system of Ferranti Ltd to show the pilot his true position on a continuously moving map in his cockpit. This unit can carry all the charts needed for any world-wide operation on a single spool of 35-mm film, any part of which can be instantly retrieved and presented on the instrument panel through the 156-mm aspheric lens which has a focal depth of 137-mm. The same precision applies whether the pilot is crossing the Indian Ocean or coming in to a mid-city landing pad. The lens itself is made from optical grade Perspex (ICI) and demonstrates the potential of this type of material in meeting exacting requirements in terms of precision and freedom from distortion.

Alternative materials which can be used for the manufacture of aspheric lenses are:

$$n\frac{20}{D} \qquad V = \frac{nD - 1}{nF - nD}$$

	Refractive Index	*Dispersion Factor*
Acrylic	1.492	57
Polystyrene	1.57	31

These materials offer combinations suitable for removal of chromatic aberration. Both materials have the clarity of glass and high transmission ability both to visible and ultra violet light. Materials are available with a wide uv transmission.

C. E. Hammer (left) and A. M. Becraft of the Air Force Avionics Laboratory.