**Impurity Absorption Spectroscopy of the Deep Double Donor Sulfur in Isotopically Enriched Silicon**

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**Introduction**

Isotopically enriched Si opens new spectroscopic possibilities by eliminating inhomogeneous broadening.

- **Si** isotope enrichment [9], 99.991% 28Si
- Sample purity: 2 x 10^-13 cm^-3 P, 5 x 10^-13 cm^-3 B
- Isotope enrichment: 92.2% 28Si + 4.7% 29Si + 1.1% 30Si

**Experimental Method**

**Fourier Transform Spectroscopy**

- Benten DAS Fourier-transform spectrometer.
- Resolution: 0.0024 cm^-1 (broad beam), 0.0017 cm^-1 (narrow beam)
- Sample conditions: Glodra, Quartz lamp
- Beam splitters: KBr and CaF2
- Detectors: HgCdTe, InSb

**Sample Preparation**

- Si plus sulfur sealed in ampule
- Ampule kept in furnace for 20 h at 1100°C
- Quench into methanol, polish and etch.

**Deep Double Donor Sulfur**

Valley-orbit splitting of 6-fold degenerate 1s ground state together with spin-orbit splitting leads to Γ1'-Γ3' splitting of the 1s(2s) transition.

The 1sA1 → 1sT2 transition is EMT forbidden, symmetry allowed [2, 3].

**S + 1s(2s) in Si**

- Γ1 Si isotope effect
- Γ2 Si isotope effect
- Γ3 due to changes in the nearest-neighbour LVM energy of the S2i cluster of the substitutional S atom [4].

**S + 1s(2s) in 28Si**

The LVM satellites are eliminated.

Energy shift between 28Si and 29Si in 28Si is

\[ \Delta E(29Si) = \Delta E(30Si) = -0.56 \text{ cm}^{-1} \]

confirms previous result for 32S 1s(2s) [1].

**S + 1s(2s) in 28Si**

The 1sA1 → 1sT2 transition is the narrowest donor/acceptor absorption line in silicon to date.

- 22 × narrower than in previous S spectra [4]; 2.5 × narrower than in previous P and B spectra [6].

**S+ and S-Isotope Shifts**

- The 1sA1 → 1sT2 transition for 29Si lies below that of 30Si by 0.56 cm^-1, confirming the unusual isotope shift for this transition first reported by [4].
- Dependence of the binding energy on \( m_i^2 \) and \( m_s^2 \) [7] and Si neighbour-isotope effects causes energy shift

\[ \Delta E(28Si) = \Delta E(30Si) = +1.4 \text{ cm}^{-1} \]

confirming the normal sign of the ground state isotope shift [8] also seen for Bi in Si [5, 7].

Unresolved splitting of \( S + 2p_\alpha \) is resolved in 28Si [9].

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**References**